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Technical Activities 1986

Center for Radiation Research

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U.S. DEPARTMENT OF COMMERCE
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Gaithersburg, MD 20899

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U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, Secretary
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ABSTRACT

This report summarizes research projects, measurement method development, calibration and testing, and data evaluation activities that were carried out during Fiscal Year 1986 in the NBS Center for Radiation Research. These activities fall in the areas of atomic and plasma radiation, radiation physics, radiometric physics, radiation sources and instrumentation, ionizing radiation, and nuclear physics.

Key Words: Atomic radiation, ionizing radiation; measurement support; nuclear radiation; plasma radiation; radiation instrumentation, radiation measurements; radiation physics, radiation sources; radiometric physics.

INTRODUCTION

This report is a summary of the technical activities of the NBS Center for Radiation Research (CRR) for the period October 1, 1985 to September 30, 1986. The Center is one of four Centers in the National Measurement Laboratory.

The Center for Radiation Research develops and maintains the scientific competences and experimental facilities necessary to provide the Nation with a central basis for uniform physical measurements, measurement methodology, and measurement services in the areas of near infra-red radiation, optical (visible) radiation, ultraviolet radiation, and ionizing radiation (x rays, gamma rays, electrons, neutrons, radioactivity, etc.); provides government, industry, and the academic community with essential calibrations for field radiation measurements needed in such applied areas as nuclear power, lighting, solar measurements, aerospace, defense, color and appearance, health care, radiation processing, advanced laser development, and radiation protection for public safety; carries out research in order to develop improved radiation standards, new radiation measurement technology, and improved understanding of atomic, molecular, and ionizing radiation processes, and to elucidate the interaction of radiation and particles (electrons, neutrons, and ions) with inanimate and biological materials; collects, compiles, critically evaluates, and supplements the existing atomic, molecular, and ionizing radiation data bases in order to meet the major demands of the Nation for such data; and participates in collaborative efforts with other NBS centers in the interdisciplinary applications of radiation.

The summary of activities is organized into six parts, one for each of the five Divisions in the Center: Atomic and Plasma Radiation, Radiation Physics, Radiometric Physics, Radiation Sources and Instrumentation, and Ionizing Radiation, and one for the Nuclear Physics Group. A major subgroup of the Ionizing Radiation Division is the Office of Radiation Measurement. Each organizational unit tells its own story in its own way. In general there is an introduction followed by a series of short reports on current activities, publications during the year, talks given, committee participation, and professional interactions.

A detailed table of contents has been provided to permit the reader to find those activities of greatest interest. To obtain more information about particular work, the reader should address the individual scientists or their division, c/o Center for Radiation Research, Radiation Physics Building, C229, National Bureau of Standards, Gaithersburg, MD 20899.

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TECHNICAL ACTIVITIES

Division 531, Atomic and Plasma Radiation

The Atomic and Plasma Radiation Division carries out a broad range of experimental and theoretical research on atomic structure and atomic radiation in plasmas. The division determines a large variety of atomic radiation and collision data, encompassing wavelengths of spectral lines; atomic energy levels; ionization potentials; atomic transition probabilities; plasma line broadening parameters; ionization and excitation cross sections and rate coefficients, and dielectronic rate coefficients. Two data centers located in the division critically evaluate and compile atomic energy levels and transition probabilities. The division is also engaged in research on the interaction of atomic radiation with plasma environments, and it explores such effects for the development of new measurement techniques. Furthermore, well-defined atomic radiation sources are developed as VUV radiometric standards or wavelength standards.

These activities support several areas of science and technology. A good deal of our work ties into magnetic fusion research, where atomic data are needed for studies of the effects of heavy ion impurities and where atomic radiation processes are utilized as non-interfering plasma probes. Other areas of direct applications are parts of the Strategic Defense Initiative (SDI), vacuum ultraviolet and x-ray laser development, and space astronomy and solar physics. In all these areas, atomic radiation data are one of the basic ingredients, and plasma measurement techniques utilizing the emitted radiation are applied. Our vacuum ultraviolet radiometry work is now providing small calibrated radiation source packages to allow radiometric calibrations on board spacecraft, which are used, for example, on the space shuttle for accurate monitoring of the solar ultraviolet radiation, and are part of the space telescope instrumentation.

The division consists of three technical groups: Atomic Spectroscopy, Atomic Radiation Data, and the Plasma Radiation Groups. The division currently has 17 professional physicists, among them 15 Ph.D.s, plus 1 IPA. During 1986 the division has had 11 guest scientists from China (3), Israel (2), France (2), India (1), Soviet Union (1), and Yugoslavia (1).

Some of our significant accomplishments during the past year are:

- Measurements and identifications of spectral lines from very highly ionized atoms to obtain reference wavelengths for x-ray laser research and test calculated Lamb shifts.

- Critical evaluation of experimental and theoretical results available for helium 1snℓ level systems to obtain accurate ionization energies and confirm two-electron quantum-electrodynamic energy contributions.

- Calculations of electron impact excitation cross sections for very highly ionized atoms based on a fully relativistic formulation of the problem.

- Development and numerical study of upper and lower bound procedures for theoretical atomic oscillator strengths.

- Measurement of population inversion in C^{3+} in a theta pinch plasma.

- Characterization of laser-produced plasmas as irradiance source for the XUV region.

These and other activities are discussed in the following sections, where the principal work of the three technical groups during the past year is described.

I. Atomic Spectroscopy Group

(a) Highly Ionized Atoms

The wavelengths and energy levels for spectra of highly ionized atoms are necessary for diagnostics of high-temperature plasmas (tokamak plasmas, etc.) and for x-ray laser research. These spectra are also of basic interest for testing atomic calculations including large relativistic and quantum-field (QED) contributions. We have excited very highly charged ions in laser-produced plasmas using the 24-beam OMEGA laser at the University of Rochester. The charge states identified in our most recent spectra range from Au^{49+} to U^{65+}, the latter spectrum extending the Co isoelectronic sequence to the heaviest of the naturally occurring elements. Lines of Fe-like, Cu-like, and Zn-like ions were also identified (0.9 to 11 nm). Comparisons of measured wavelengths in the Cu-like spectra with relativistic calculations confirm QED contributions for the 4s-4p transitions, but significant differences remain between calculated and observed values (J. Reader and collaborators from the Naval Research Lab.).

Other high-ionization spectra obtained with the OMEGA facility which we have analyzed include F-like ions (Zr^{31+} to Sn^{41+}), O-like ions (Y^{31+} - Nb^{33+}), and the Br ions Br^{24+} and Br^{28+} - Br^{30+}.

We have given high priority to completing our measurements of spectra for the Na-like ions of elements through Sn because these wavelengths are being used as standards in the work on Ne-like ionic x-ray lasers at Livermore. Using isoelectronic smoothing of the data we are obtaining wavelengths for the Na sequence in the region 5-30 nm accurate to about ±0.0007 nm. We plan to use similar procedures in deriving wavelengths from our data for the Co and Fe isoelectronic sequences (elements Kr to U, wavelengths 1 to 10 nm). (J. Reader, et al.)

We are exciting and analyzing spectra of ions of the elements Cu to Mo stripped to the n=3 shell. Both allowed (electric dipole) and forbidden (magnetic dipole) lines are being studied. These spectra are important for tokamak diagnostics as well as x-ray laser studies, and the wavelengths in some cases will also be useful for VUV standards. We have measured and analyzed the n=3-3 transitions in Cu^{11+} through Cu^{20+} and Zn^{11+} through Zn^{18+}, and are working on similar ion stages for Ga, Ge, and As. We plan to extend this work from Se to Mo (Z=34-41) using the Texas tokamak (TEXT) as the radiation source. (V. Kaufman and J. Sugar).

The Ne isoelectronic sequence has special interest in that soft x-ray laser lines have been demonstrated in Ne-like selenium. We extended our research on this sequence to obtain the energy level structures for

Ca^{10+} through Fe^{16+}, and we probably will eventually add Co^{17+} and Ni^{18+} using the NBS laser (Kaufman, Sugar, and a Swedish collaborator, U. Litzén).

(b) Wavelength Standards (5 to 330 nm)

We completed our measurements of the spectrum of a platinum hollow-cathode discharge for the VUV and UV region 110-330 nm. We are now combining these results with measurements at longer wavelengths to optimize the energy levels and derive Ritz-principle wavelengths. The values for almost 3000 lines having uncertainties of ±0.0001 to ±0.0003 nm will be used for on-board calibration of the High-Resolution Spectrograph for the Space Telescope and also for high-accuracy laboratory spectroscopy.

Our just-published measurements of 900 Y^{5+} lines include accurate Ritz-type wavelengths for 225 lines in the XUV region 18-40 nm. Together with our previous Y^{3+} determinations and our Y^{4+} work still in progress, these wavelengths comprise a system of yttrium standards for the range 18-70 nm.

At a lower accuracy level, our ongoing measurements of lines in the spectra of Fe ions, Fe^{15+} to Fe^{19+}, are being used for standards in the 5-13 nm region (uncertainties ~±0.0005 nm). Use of our wavelengths now being obtained for the Na isoelectronic sequence as standards was noted above (J. Reader and N. Acquista).

(c) Ionization of Lithium Vapor by CW Quasiresonant Laser Radiation

In the course of assembling apparatus for observation of Rydberg states of atomic Li, we noted that laser radiation tuned to the 2p-3d transition of Li was strongly absorbed in the vapor despite the fact that the 2p state is not thermally populated. Further observation showed that the absorption was accompanied by strong fluorescence and ion production. Similar effects have been observed in Na and Cs in other laboratories, but for these species the effect was produced only for broadband laser pumping. In Li the absorption was very strong for single frequency radiation. By making a systematic study of the dependence of the vapor transparency, ion production, and fluorescence spectrum on vapor density, laser power, and laser tuning, we were able to determine the hybrid molecular/atomic processes by which the absorption proceeds. In a sequence of steps including a molecular absorption, atomic/molecular excitation transfer, a saturated atomic absorption, and an atomic energy-pooling collision the vapor reaches an equilibrium condition in which there is a high density of hot 2p and 3d atoms. From this state ions can be produced by direct photoionization or associative ionization. (C. J. Sansonetti and D. Veza)

(d) Energy Levels, Ionization Energy, and Lamb Shifts in Helium

High-accuracy wavelength measurements in helium are of fundamental interest for testing relativistic and QED (quantum electrodynamic) contributions to energy levels of this basic two-electron system. We have combined experimental energy-level determinations with theoretical calculations to derive a new value for the ionization energy of ^{4}He I accurate to ±12 MHz with respect to the 1s2s ^{3}S level. The entire 1s$n\ell$ level system is determined with relative accuracies of 10-20 MHz except for a few low levels. Values for the Lamb shifts of 1sns and 1snp levels yielded by the data give the first confirmation of predicted two-electron QED contributions and reveal large errors in available Lamb-shift calculations for 1sns terms (n=3-5). Improvement of these results to accuracies of 1 to 3 MHz will allow much more rigorous tests of two-electron QED energies, and also test relativistic-recoil shifts, nuclear-size effects, and higher-order QED contributions that have never been confirmed (some have not yet been calculated). These accuracies can be achieved with laser spectroscopy and an atomic-beam source. We expect to carry out the needed wavelength measurements as the first use of a new atomic-beam source now being designed. (W. C. Martin, C. Cromer, C. J. Sansonetti)

(e) Atomic Energy Levels Data Center

Our new energy-level compilations for the 235 spectra of the iron-group elements potassium through through nickel (Z=19-28) were published in a one-volume supplement to the J. Phys. Chem. Ref. Data. (J. Sugar and C. Corliss)

We completed and published the most extensive compilation of data for (forbidden) magnetic-dipole transitions ever carried out. The data include 1660 predicted wavelengths and transition probabilities (10 nm to 26 mm) for atoms and ions of the elements beryllium through molybdenum. These tables will be used extensively for diagnostics and analysis of radiation from laboratory (tokamak, etc.) and astrophysical plasmas. (V. Kaufman and J. Sugar)

We have completed critical evaluation and compilation of the energy-level data for more than half of the 42 spectra of molybdenum, an element of special interest for tokamak-discharge diagnostics. (J. Sugar). A separate compilation giving wavelengths and energy-levels classifications for the spectra of Mo^{5+} through Mo^{41+} is almost ready for submission for publication. We also collaborated with the Japanese group on a similar compilation for spectra of the nickel ions Ni^{8+} through Ni^{27+} (manuscript in preparation). (J. Sugar and Japanese collaborators)

We are critically reviewing and compiling data on energy levels for the spectra of sulfur and chlorine. The results of new calculations, theoretical interpretations, and measurements stimulated by our reviews are being included in these compilations. (W. C. Martin, R. Zalubas, A. Robey)

We monitor the literature on atomic energy levels, wavelengths, wavefunctions, etc., and the resulting reference files and published bibliographies are used by a wide clientele. We plan a fourth supplement to our Bibliography on Atomic Energy Levels and Spectra, covering the period from January 1984 through December 1987. (A. Robey, R. Zalubas)

II. Atomic Radiation Data Group

The work of this group is entirely theoretical and consists of two major areas: (1) theoretical studies of atomic structure and processes, and (2) critical evaluation and compilation of atomic transition probability and spectral line shape data. The first activity involves the development of advanced theoretical methods and their implementation to calculate atomic data. The main areas of activity have been dielectronic recombination, relativistic quantum mechanics, electron correlation, and radiative and collisional transition rates. The critical evaluation and compilation of transition probability and spectral line shape data takes place in the Data Center on Atomic Transition Probabilities, which also maintains an up-to-date bibliography of the literature in these fields.

(a) Theoretical Studies

The comprehensive dielectronic recombination computer codes have been used to calculate total recombination rates for highly stripped ions in a hot plasma. Work has been completed on selected ions in the lithium, fluorine and oxygen isoelectronic sequences, and papers describing this research have been submitted for publication. In addition to the data for the ions actually computed, these studies also include empirically derived formulas for interpolating recombination rate data for other ions of these sequences. The influence of the metastable excited states of the ground configuration on the dielectronic process has also been studied for the ions Fe XX, Fe XIX, and Fe XVIII. In addition, we are now wrapping up our studies of dielectronic satellites in lithium-like ions.

Currently, these codes are being revised and expanded to include the effects of intermediate coupling and configuration interaction in the target ion, dielectronic states and final states. We have also developed exact analytic expressions for matrix elements when the core wave function is represented analytically, and the continuum and Rydberg orbitals are well represented by a hydrogenic approximation. This development, which allows the rapid computation of radiative and autoionization rates, has also been incorporated into the programs. (L. J. Roszman)

Our relativistic distorted wave programs for computing electron impact excitation cross sections are now operational and have begun to produce results for excitations in ions with alkali-like configurations. These codes are fully relativistic in that they represent all electrons by four-component Dirac spinors, both the scattering electron as well as those in the target ion, for which the wave function is normally a correlated, relativistic wave function. For the high incident energies encountered in the highly ionized ion regime, it has been necessary to go to a very large number of partial waves in the distorted wave expansion, and then to extrapolate the remainder by connecting with the plane-wave Born approximation, and a great deal of our efforts were devoted to implementing this procedure. It is expected that, for very highly charged ions, relativistic effects should be important, not only for the target ion, but also for the scattering electron; results obtained for Xe^{51+} show significant departures from the nonrelativistic calculation, particularly in the $2s \rightarrow 2p_{1/2}$, $2p_{3/2}$ excitations. (Y.-K. Kim)

We have also intensively examined the problem of theoretically bounding quantum mechanical matrix elements, in particular as a means of establishing upper and lower bounds for theoretical oscillator strengths. A number of theorems have been proved and a variety of bounding procedures developed, and we have begun to apply them in test calculations on a multi-electron atom. For this purpose we have selected the lithium atom resonance transition using the Hartree-Fock approximation, which is known to produce fairly accurate results for this transition. The point is to test the bounding procedures, to explore their limitations and strengths, and to determine which is likely to be the most useful. We have also done accurate correlation calculations to provide a standard and information on what will contribute most to improving the f-value and its bounds. Our work to date has yielded a total error width of 10%, with the lower bound much closer than the upper bound. (A. W. Weiss and D. Roginsky)

The studies of 3d-shell collapse have led us to a series of calculations on the $3p^5 3d$ states of the argon isoelectronic sequence, probably the simplest example where strong state-dependent shell collapse effects occur. While our treatment of correlation is somewhat limited, it is far more extensive than is usually done for such a system. We find that it is essential to include not only 3p-3d and 3s-3d correlation, but also, unfortunately, 3p-3p and 3s-3p correlations which are strongly state dependent due to the possibility of excitations into the term-dependent and collapsing 3d shell. As of this writing, there are ambiguities in our results which are not yet fully understood. (A. W. Weiss)

During the past year, we hosted a number of atomic theorists, some for an extended period of time, and some as regular weekly visitors.

P. M. Mohr (NSF) spends one day a week with us working with Y.-K. Kim on computational aspects of QED problems. They have recently completed a set of calculations of the Lamb shift for n=3 levels of hydrogen-like ions, and they now believe they are beginning to see the pattern of QED corrections for highly charged hydrogen-like ions as a function of principal quantum number.

M. A. Ali (Howard Univ.) also spends one day a week here, working with Dr. Kim on relativistic atomic structure calculations for heavy and highly charged ions.

J. P. Desclaux (Grenoble) spent the month of May with us again this year, working with Dr. Kim on relativistic continuum electron codes. These programs were the ones used for the relativistic scattering calculations described above. Dr. Desclaux's visit was partially supported by a NATO research grant.

U. I. Safronova (USSR) also visited us for one month in November 1986. She consulted extensively, and intensively with Drs. Kim and Weiss on the relativistic correlation problem, as well as with a number of the members of the spectroscopy group.

D. V. I. Roginsky (Israel) has spent the entire year with us studying the problem of bounding theoretical oscillator strengths. He has worked closely with A. W. Weiss on this problem, a collaboration which has proved mutually stimulating.

L. Woltz (Florida) has also been with us over the past year, collaborating with L. Roszman and W. L. Wiese on problems in the theory of spectral line broadening.

(b) <u>Data Center on Atomic Transition Probabililty</u>

Critical evaluations and tabulations of atomic transition probability data for the iron group elements, scandium through nickel, has continued. The research activity in this field is very strong, propelled by the interests of two user communities, namely the astrophysicists and the fusion community. This has meant that new and revised data are continually becoming available, and we attempt to include this material to the greatest extent possible, revising and adding to existing data tables. This influx of new data has slowed the pace of our work somewhat, although we feel that we are making steady progress. During the past year, we have completed the evaluation of both allowed and forbidden lines for all ions isoelectronic with sulfur, phosphorus, silicon, aluminum, and magnesium. Tabulations of the forbidden lines of neutral and low ionization stages of all the elements, Sc through Ni, have been completed, as have the forbidden lines of ions in the oxygen, fluorine and neon sequences.

We continually monitor the literature, maintaining an up-to-date bibliography on site. Also, we continue to supply, in regular intervals, bibliographical reference material for inclusion in the "International Bulletin on Atomic and Molecular Data for Fusion," published by the International Atomic Energy Agency. Our input is their principal, and often only, source of spectroscopic references. We are currently learning how to utilize an IBM PC for data evaluation applications as well as for bibliographic purposes.

III. Plasma Radiation Group

Our plasma measurements program provides valuable data and measurement techniques for fusion diagnostics, plasma densities, VUV radiometry, and VUV lasing schemes. The activity in collisional rate coefficients is of critical importance in plasma modeling, especially fusion-type plasmas and VUV laser schemes. The research on line shapes and scattering has impact on gain measurements in lasing media as well as fundamental measurements of plasma densities. Our portable radiometric standards have been used for many spacecraft calibrations and are still in demand for that purpose.

(a) Collisional Rate Coefficients with the 50kJ Theta Pinch

Ti^{9+} relative excitation rate measurements were accomplished from experiments on the NBS 50kJ theta pinch. These results were compared with distorted wave calculations, and agreement between experiment and theory was found within combined uncertainties. A procedure to account for opacity in certain Ti^{9+} transitions was also applied. These rates will be used in plasma modeling where titanium is an impurity from e.g. walls or limiters. (R. Datla, J. Roberts)

Experimental conditions were investigated to observe a recombination phase of the theta pinch plasma. An electron density of 3×10^{16} and an electron temperature from 20-30 eV was generated in a C_2H_2 plasma. The recombination into C^{3+} showed a population inversion in the n=4 levels compared with the n=3 levels. The population ratio of the 4f/3d was measured to be 4.5 which would be sufficient to give a substantial laser gain in the 1165 Å C^{3+} transition for our 28 cm long plasma. Further investigation indicated the ion temperature to be approximately 1 keV from Doppler line widths. Thus the effective gain in the 1165 Å transition is substantially reduced because of its Doppler width of 1-2 Å. Further investigations with different theta pinch configurations maintaining this inversion ratio are hoped to bring the ion temperature down so the gain per unit length is sufficient to make this an attractive lasing medium. If successful this will provide valuable data on VUV lasing methods using sources such as a theta pinch. (R. Datla, J. Roberts)

(b) Tokamak Spectroscopy

More than 35 spectral lines from magnetic dipole (M 1) transitions were reported from observation of the Texas Experimental Tokamak (TEXT). About a third of these were in the air portion of the spectrum above 2000 Å, making them easily observable and usable for experiments on ion temperature measurement and ion transport studies in tokamaks. (J. Roberts, R. Datla, T. Pittman, J. Sugar, V. Kaufman)

First time ever measurements of absolute excitation rate coefficients in highly ionized elements have been reported using the TEXT tokamak. Based on the absolute radiometrically calibrated measurements of emission spectral lines, both M 1 and the electric dipole lines of interest, Cl-like and Al-like Fe, Ni, Cu, and Zn excitation rates were measured. Many of the previously measured M 1 lines permitted the absolute number density of the ion ground state to be measured. SURF II and branching ratio calibrated spectrometers in the XUV and VUV spectral region down to 150 Å were used to measure the absolute spectral line intensities. Combining these two critical measurements yielded the absolute excitation rate coefficient measurement. (R. Datla, J. Roberts)

(c) Autoionization in Electric Fields

We have observed the effects of d.c. electric fields on highly excited levels of Ba and Gd. The "Rydberg manifold," or fanning out of levels as the field increases, is quite different than previously observed. In a detailed theoretical treatment we showed that this difference arises from the anisotropic character of the ionic core of the doubly excited atom. This gives rise to many additional fine structure components where presence gives rise to quite complex spectra, particularly in the presence of electric fields.

In a recently submitted manuscript we present an algorithm for computing the complex manifold structure in "jK coupling," and obtain excellent agreement with our experimental spectra. (D. Kelleher)

(d) Calculation of Spectral Line Shapes for Ions in Plasmas

We have recently completed a calculation of the collisional broadening of the Balmer alpha ($n=3 \rightarrow 2$) lines of C^{5+} in a plasma. The alpha line is the lasing transition (183 Å) of interest in x-ray laser schemes being investigated at Princeton and also at Livermore. Above a certain electron density, the collisional broadening will become large enough to quench the lasing. It is critical in laser design to have a reliable estimate of this density (the beta transition, $n=4 \rightarrow 2$, can be used to estimate the experimental density). Our theoretical method utilizes a numerical simulation to derive the time dependent fields of the perturbing ions, and an analytic approach to determine the subsequent line shape. We are in the process of generalizing the method to include fine structure so that it can be applied to transitions in the entire region from degenerate to isolated levels. This work is supported by the Air Force Office of Scientific Research. In collaboration with J. Cooper of JILA, we are also developing an entirely analytic theory, which approximates the strong collisions by a nearest neighbor model. (D. Kelleher, D. Oza)

(e) Vacuum Ultraviolet Radiometry with Plasmas

Previous to this year we calibrated the irradiance of the Space Telescope Optical Simulator (STOS), which was then used to calibrate the Faint Object Spectrograph (FOS), one of the instruments on the Space Telescope. Upon completion of calibration, the FOS and the other instruments were incorporated into the Space Telescope, which is to be deployed in orbit by the Space Shuttle. In the past year we performed fourteen calibrations of three Pt-Cr-Ne and five Pt-Ne hollow cathode lamps which were then used in preflight throughput tests of the Space Telescope with its installed instruments. In addition to the FOS, the instruments are the high resolution spectrograph, the wide-field planetary camera, the faint object camera, and the high speed photometer. The recently completed throughput tests were highly successful and even more useful than projected. As a result, we are now beginning preparations for a post-throughput test calibration of the hollow cathode lamp. (J. Klose, M. Bridges)

Another major project of the past year has been the documentation of our calibration services. An exhaustive treatment has been carried out to put on record a detailed description of our calibration program in the vacuum ultraviolet. (J. Klose, M. Bridges)

Work is also continuing with laser-produced plasmas as sources of irradiance in the far UV region. This effort is directed toward development of a standard irradiance source in the spectral region which would be available to anyone with access to a pulsed laser of modest energy. Both Nd:YAG and ruby lasers have been used. Observations completed so far include quantitative high resolution spectra from different target materials in order to identify those giving a most suitable spectral output, i.e. a sufficiently intense continuum relatively free of lines over some spectral range. Present efforts involve measuring the spectral irradiance dependence on laser energy, quality of laser focus on the target, and beam quality of the laser. This characterization of the source determines the irradiance for a given setup, i.e. laser, target material and geometry, and focussing optics. To measure the irradiance on an absolute basis, a spectrometer was calibrated at SURF. Measurements with this instrument are being made to calibrate the irradiance from the laser-produced plasma sources. (M. Bridges)

(f) Stark Broadened Widths and Shifts of Non-hydrogenic Ion Lines

We have completed the experiments observing the Stark broadening of spectral lines in the noble gases. Spectral lines from both the first and second ionization stages of Ne, Ar, Kr, and Xe were observed in this study. We found that irregularities in the trend along the homologous sequence of these gases can occur when there exist perturbing level(s) near the upper or lower energy level of the emitting ion. Nearby perturbing levels can cause additional broadening of some lines and must be considered when interpolating new data along a sequence.

We also measured the broadening of spectral lines from states of high orbital angular momentum in singly ionized nitrogen. The measurements were compared with two theories having different approaches in treating the form of coupling in the atomic structure of these lines. Our results could not definitively determine which approach was more suitable and concluded that additional theoretical work was necessary.

A He-Ne laser quadrature interferometer was used to determine the electron densities in the above studies. The temperature was determined using a Boltzmann plot of relative intensities of O II impurity lines.

At this time we are conducting new experiments observing the width and shift of lithium-like beryllium ion lines. We have demonstrated the feasibility of introducing beryllium into a helium plasma using a laser ablation technique. Studies determining the plasma equilibrium and distribution of beryllium in the discharge have begun. We have made preliminary measurements of Be^+ spectral line profiles and have encountered some unexpected results. Hydrogen-like line profiles were not always observed. For instance, the 3p $^2P^o$ - 4d ^2D Be^+ transition showed a line profile that was strongly asymmetric and included a feature in the line wing resembling a forbidden component line. Detailed study of these lines will continue using a more advanced multichannel detector. This work in ionized beryllium is a natural step progressing from our earlier work on the width and shift of ionized helium lines. (T. Pittman)

(g) Rayleigh Scattering and Near Resonance Fluorescence

Experimental results have been accomplished using the near resonance Rayleigh scattering (NRRS) technique. The NRRS technique involved the generation of a plasma column in a Ba vapor heat pipe with the resonant ionization processes using a flashlamp pumped laser called the pump laser. Simultaneously and collinearly a Nd:YAG principal dye laser (probe laser) tuned near the Ba^+ resonance lines at 553.6 nm is used for the scattering measurements. The probe laser beam is substantially smaller in diameter than the pump laser. Thus the right angle scattered radiation must traverse the plasma before detection and may suffer from radiation trapping. The first experiment investigated this opacity problem and provided a simple solution to ensure opacity effects do not contribute to the interpretation of the observed signal. The second experiment measured the temporal and spatial evolution of the absolute density of Ba^+ in the plasma column. The results of this experiment show a substantial difference between these local temporally resolved measurements and the line integrated measurements of previously investigations. The third experiment measured the depolarization of the NRRS signal as a function of detuning of the probe laser over the Ba^+ resonance transition. Comparison of the measurements with theory showed very good agreement. (A. Nee, G. Chen)

INVITED TALKS

Division 531, Atomic and Plasma Radiation

Kelleher, D. H., "Electric Field Effects on Structure in the Continuum," Conference on Photon and Continuum States of Atoms and Molecules, Cortina, Italy, June 16-20, 1986.

Kim, Yong-Ki, "Relativistic Effects in Atoms and Molecules," Chemistry Department Colloquium, Howard University, Washington, DC, February 14, 1986.

Kim, Yong-Ki, "Energy and Angular Distributions of Secondary Electrons," Physikalisches Institut der Universität Tübingen, West Germany, June 13, 1986.

Kim, Yong-Ki, "Relativistic Effects in Electron-Atom Collisions," Symposium on Relativistic Many-Body Problems, Trieste, Italy, July 3, 1986.

Kim, Yong-Ki, "Relativistic Effects in Electron-Ion Excitations," Joint Workshop of U.S.-Japan Fusion Collaboration Program, Institute of Plasma Physics, Nagoya University, Nagoya, Japan, September 2, 1986.

Martin, W. C., "Research on Atomic Spectroscopy at NBS," Symposium on Atomic Spectroscopy, Lund University, Sweden, November 4, 1986.

Sansonetti, C. J., Classical Methods for Precision Wavelength Metrology," NBS Staff Research Seminar, December 4, 1985.

Sugar, Jack, "Critical Compilation of Atomic Energy Levels and Transition Probabilities," Colloquium on Atomic Spectra and Oscillator Strengths for Astrophysics and Fusion Research, Toledo, Ohio, August 11, 1986.

Wiese, W. L., "Improvements in Atomic Transition Probability Data," Working Group on Atomic Transition Probabilities, General Assembly of the International Astronomical Union, New Delhi, India, November 1985.

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Wiese, W. L., "Ion Broadening of Heavy Element Lines in Plasmas," 8th International Conference on Spectral Line Shapes, Williamsburg, Virginia, June 9, 1986.

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Wiese, W. L. and Jones, Douglas W., Ion Broadening of Heavy Element Lines in Plasmas, as Proceedings for 8th International Conference on Spectral Line Shapes, in _Spectral Line Shapes_, Vol. 4 [in press].

Woltz, L. A., Quasi-Static Ion Broadening of Isolated Spectral Lines [in press].

PUBLICATIONS IN PREPARATION

Division 531, Atomic and Plasma Radiation

Brewer, L. R., Buchinger, F., Ligare, M., and Kelleher, D. E., Resonance-Enhanced Multiphoton Ionization of Atomic Hydrogen (in preparation).

Chen, Guoxong and Nee, T.-J., Depolarization of the Near-Resonance-Rayleigh Scattering by Barium Ions (in preparation).

Chen, Guoxong and Nee, T.-J., A Local Measurement of Ba^+ Density Temporal Evolution (in preparation).

Clark, Charles W., and Kelleher, D. E., Quadrupole Moments and Tensor Polarizabilities from Fine Structure Splittings of Non-Penetrating Orbitals (in preparation).

Datla, R. U., Roberts, J. R., Mann, J. B., Electron impact excitation of Ti X (in preparation).

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Jones, Douglas W., Pichler, G., and Wiese, W. L., Asymmetries in spectral lines due to plasma ion broadening - Some unusual cases and a possible test for plasma homogeneity, submitted to Phys. Rev.

Kelleher, D. E. and Saloman, E. B., The Stark effects of Rydberg levels with an isotropic ion core (in preparation).

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Nee, T. A., Calculation of Helium Plasma Satellites in Turbulent Plasmas (in preparation).

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Roszman, L. J., The dielectronic recombination rate coefficients for ions of the oxygen isoelectronic sequence, submitted to Phys. Rev. A.

Roszman, L. J., The dielectronic recombination rates for ions of the nitrogen isoelectronic sequence, (in preparation).

Roszman, L. J., The influence of ground configuration in metastable states upon the dielectronic recombination of impurity ions in moderate density plasmas (in preparation).

Seely, J. F., Ekberg, J. O., Brown, C. M., Feldman, U., Behring, W. E., Reader, J., and Richardson, M. C., Laser-Produced Spectra and QED Effects for Fe-like, Co-like, Cu-like, and Zn-like Ions of Au, Pb, Bi, Tb, and U (submitted to Phys. Rev. Lett.).

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Veza, D. and Sansonetti, C. J., Ionization of lithium vapor by cw quasiresonant laser radiation (in preparation).

Weber, J.-H. and Sansonetti, C. J., Accurate energies of nS, nP, nD, nF and nG levels of neutral cesium (submitted to Phys. Rev. A).

TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION AND LEADERSHIP

Division 531, Atomic and Plasma Radiation Division

Daniel E. Kelleher

Member, International Organizing Committee of the Conference on Spectral Line Shapes.

Yong-Ki Kim

Member of Program Committee, APS Topical Conference on High Temperature Plasmas.

Georgia Martin

Chairperson, NAS/NRC Committee on Line Spectra of the Elements - Atomic Spectroscopy.

William C. Martin

Chairman, Working Group on Structure of Atomic Spectra, International Astronomical Union.

Member, IAEA Network of Atomic Data Centers for Fusion.

James R. Roberts

Member of TEXT Users Organization.

Jack Sugar

Member, OSA Fellows and Honorary Members Committee.

Member, NAS/NRC Committee on Line Spectra of the Elements - Atomic Spectroscopy.

Wolfgang L. Wiese

Member of Organizing Committee, International Astronomical Union, Commision on Fundamental Spectroscopic Data.

Chairman, Working Group on Atomic Transition Probabilities, International Astronomical Union, Commission 14.

Member, IAEA network of Atomic Data Centers for Fusion.

Division 531, Technical and Professional Committee Participation and Leadership (cont'd.)

Wolfgang L. Wiese

Member, OSA Meggers Award Committee.

Co-Chairman, US-Japan Workshop on "Tokamak Diagnostics by Visible, VUV and X-ray Radiation," Nagoya, Japan.

MAJOR CONSULTING AND ADVISORY SERVICES

Division 531, Atomic and Plasma Radiation

1. The Data Centers on Atomic Energy Levels and Transition Probabilities routinely fill requests for atomic data or literature information submitted by scientists in a wide range of research areas. The requests average about 30 per month. On occasion, special reports are prepared for particular user groups. Thus, W. C. Martin and W. L. Wiese write updates on atomic data of interest for the astrophysical community for the IAU Transactions, and give review reports at the General Assemblies of the International Astronomical Union.

3. Y.-K. Kim serves as a consultant to the A Division of the Lawrence Livermore Laboratory on x-ray laser development.

4. J. Z. Klose performed numerous tests and calibrations of five Pt-Ne and three Pt-Cr-Ne hollow cathode lamps this year as part of contract work with Martin Marietta Aerospace. His work involved close consultation with Martin Marietta personnel concerning the results of each test and plans for successive tests and calibrations.

5. W. C. Martin and J. Reader have consulted and advised NASA scientists and other astronomers on standard wavelengths for calibration of the High-Resolution Spectrograph for the Space Telescope.

6. J. Reader consulted with members of the x-ray laser program at Lawrence Livermore National Laboratory about the spectra of highly ionized atoms in laser-produced plasmas and the wavelength calibration of such spectra.

7. J. R. Roberts serves as a member of the TEXT Users Organization (TUO). TEXT stands for Texas Experimental Tokamak and is a national plasma users facility. The TUO steering committee considers the special needs of off-site user groups and has provided advice and perspective on the users program to the TEXT managers and the Office of Fusion Energy at DOE.

8. L. J. Roszman provided consulting activities on various electron-ion collision processes and high density plasma modeling for x-ray laser research and development in the Lawrence Livermore National Laboratory A and Physics Divisions.

9. L. J. Roszman advises and consults with the Impurity Transport Modeling Group of the Princeton Plasma Physics Laboratory on electron-ion collision processes and other atomic data as well as the modeling of low density plasmas.

10. J. Sugar and W. L. Wiese consulted and advised the Japan Atomic Energy Research Institute (JAERI) on the compilation of spectral lines.

JOURNAL EDITORSHIPS

Division 531, Atomic and Plasma Radiation

J. Reader, Editor, Line Spectra of the Elements, Handbook of Chemistry and Physics, CRC Press.

W. L. Wiese, Associate Editor, Journal of Quantitative Spectroscopy and Radiation Transfer.

TRIPS SPONSORED BY OTHERS

Division 531, Atomic and Plasma Radiation

Victor Kaufman worked at the Zeeman Laboratory of the University of Amsterdam making spectroscopic observations and measurements of Cℓ III and Cℓ IV. All expenses including airfare and per diem were paid by the Zeeman Laboratory (June, July 1986).

Yong-Ki Kim traveled to Lawrence Livermore National Laboratory to consult with the members of A Division on X-ray lasers. Expenses were paid by LLNL (April 1986).

Yong-Ki Kim traveled to Grenoble, France to collaborate with J. P. Desclaux of the French AEC on the development of Relativistic Continuum Wavefunction Codes. The trip was paid fully from a NATO research grant (June 1986).

Yong-Ki Kim traveled to Trieste, Italy to participate in the Symposium on Relativistic Many-Body Problems. Trip was fully paid by the International Center for Theoretical Physics in Trieste (July 1986).

W. C. Martin traveled to Lund, Sweden, to participate in a symposium on atomic spectroscopy at the University of Lund in honor of Professor Bengt Edlén's eightieth birthday. All expenses were paid by the University of Lund (November 1986).

J. Reader traveled to the Lawrence Livermore National Laboratory to consult with members of the x-ray laser program about the spectra of highly ionized atoms in laser-produced plasmas and the wavelength calibration of such spectra. Trip was paid for by LLNL (August 1986).

L. J. Roszman traveled twice to the Lawrence Livermore National Laboratory to consult with an R-Program group led by Dr. S. Dalhed. Both trips were paid for by LLNL (February, July 1986).

J. Sugar attended the Colloquium on Atomic Spectra and Oscillator Strengths for Astrophysics and Fusion Research at the University of Toledo in Toledo, Ohio. The conference paid for a portion of the trip (August 1986).

W. L. Wiese traveled to Toledo, Ohio and gave an invited talk at the Colloquium on Atomic Spectra and Oscillator Strengths for Astrophysics and Fusion Research at the University of Toledo. They paid his airfare and partial per diem (August 1986).

CALIBRATION SERVICES PERFORMED

Division 531, Atomic and Plasma Radiation

Type of Service	Customer	SP 250	No. of Tests
Hollow Cathode Lamp	Martin Marietta	Contract	5
UV Spectral Radiometer	Perkin Elmer	40040S	1
Deuterium Lamp	Univ. of Colorado	40030S	1
Deuterium Lamp	NRL	40030S	1

SPONSORED SEMINARS AND COLLOQUIA

Division 531, Atomic and Plasma Radiation

Munir Nayfeh, University of Illinois, "Atomic Engineering of Giant Dipole Atoms," October 10, 1985.

K.-T. Lu, Graduate School, USTC, Academy of Sciences, Beijing, "On the Formation and Structures of Excimers: Triatomic Hydrogen and Fermi--Complexes," October 15, 1985.

Dan Roginsky, Racah Institute of Physics, Hebrew University of Jerusalem, "Novel Error Bounds for Atomic Oscillator Strengths," October 28, 1985.

Kurt Behringer, Joint European Torus (JET), Culham, England, "Spectroscopic Diagnostics on the JET Tokamak," November 1, 1985.

U. I. Safronova, Institute of Spectroscopy, USSR Academy of Science, "Dielectronic Satellites of Highly Charged Ions," November 4, 1985.

Dipak Oza, Louisiana State University, "Electron Scattering by Hydrogenic Targets: Close-Coupling Methods," December 12, 1985.

Masahide Ohno, Institute of Physics, University of Bonn, West Germany, "g-Hartree ab initio Calculation of Atomic Ionization Energies," February 26, 1986

Stephen Younger, Lawrence Livermore National Laboratory, "The Importance of Atomic Physics for X-ray Lasers and Thermonuclear Fusion," March 4, 1986.

Sveneric Johansson, Department of Physics, University of Lund, Sweden, "Laboratory and Stellar Spectra of Iron-Group Elements," March 6, 1986.

Robert Cowan, Los Alamos National Laboratory, Los Alamos, New Mexico, "Calculations of Atomic Energy Levels and Spectra with Applications to Photoelectron Spectra and Dielectronic Recombination Rates," May 13, 1986.

Lars Engström, Argonne National Laboratory, Argonne, Illinois, "Differential Lifetime Measurements as a Probe of Atomic Structure," May 27, 1986.

Jean-Paul Desclaux, Centre d'Etudes Nucleaires de Grenoble, France, "High-Precision Energy Level Calculations of Two-Electron Ions," May 28, 1986.

Keishi Ishii, Kyoto University, Kyoto, Japan, "The Cobalt Isoelectronic Sequence," July 18, 1986.

Peter Hagelstein, Lawrence Livermore National Laboratory, "Relativistic Atomic Physics Calculations for Model Making,", August 6, 1986.

Indrek Martinson, University of Lund, Sweden, "Recent Advances in Lifetime Measurements for Multiply Ionized Atoms," August 22, 1986.

TECHNICAL ACTIVITIES

Division 533, Radiation Physics

The Radiation Physics Division focuses on measurement programs relating to the use of electron, laser, ultraviolet, and soft x-ray radiation in the energy range from about 5 eV (250 nm) to 500 eV (2.5 nm).

In support of this mission, radiation standards and advanced measurement techniques are developed. Through our standards program, the Division provides the central national basis for the measurement of far ultraviolet and soft x-ray radiation. The NBS synchrotron radiation facility and a detector calibration facility based upon well-characterized photoionization chambers serve as national radiation standards. Measurement services are available for the calibration of the quantum efficiency of UV photodiodes and the spectral responsivity of vacuum ultraviolet spectrometer systems.

Through our electron measurements program, new types of electron sources and detectors are developed to investigate the properties of matter on an atomic scale. For example, specially designed spin-polarized electron sources and detectors are used to determine fundamental atomic scattering properties and to measure surface magnetism. An electron tunneling device is being developed to provide "images" of surfaces on an atomic scale and to study relationships between macroscopic material properties and surface microstructure.

With the goals of improving standards and understanding the fundamental physical phenomena upon which they are based, the Division also conducts theoretical and experimental research on the electronic structure of atomic and molecular systems, the interaction of the systems with photon and electrons, and radiation deposition and energy transfer processes. Theories are developed for the scattering and transport of electrons in materials of fundamental and technological interest. New techniques and instrumentation are developed to study radiative reactions with matter, including photoexcitation and photoionization processes and non-linear effects in intense laser fields. Studies are underway to investigate to what extent the properties and behavior of atomic systems can be manipulated by measuring and controlling atomic and molecular states in their local environment.

The Division has two major research facilities, a dedicated synchrotron ultraviolet radiation facility (SURF-II) and a polarized electron research facility.

SURF-II is a dedicated synchrotron radiation facility, consisting of a 300 MeV electron storage ring, a 10 MeV microtron injector, and associated synchrotron radiation beam lines. It produces radiation in a narrow, intense, highly polarized beam with a continuous and accurately known spectrum from the infrared through the visible and into the far ultraviolet. SURF-II is unique among synchrotron light sources by virtue of its uniform and precisely known circular orbit. This allows accurate determination of all the spectral and geometrical properties of the radiation and hence its use as an absolute radiometric standard.

This facility serves staff from our own Division, users from other NBS Divisions, and outside users in radiometric standards and calibration work, optical physics research, surface science, biochemistry, spectroscopy, and other research areas utilizing far ultraviolet radiation. It fills a growing demand for radiation in the ultraviolet and soft x-ray region of the electromagnetic spectrum. Of the 11 light ports at SURF, 6 are now instrumented for user applications and for calibration of optical instruments and transfer standard photodiodes. Some of these ports are shared by more than one experimental station. Three of the remaining ports are utilized for beam current monitoring, electron counting, and machine diagnostics. Most experiments and calibrations can run simultaneously, unless they require special beam parameters.

The polarized electron scattering facility is used to produce and measure beams of spin polarized electrons and is available for collaborative research by NBS and outside scientists in areas of mutual interest on a time-available basis. Three separate, ultra-high vacuum instruments are available. The polarized electron beams have currents in excess of 1 μA, with an optically reversible polarization at energies less than 1 KeV and with an energy resolution of ≈ 0.15 eV.

These electrons are used to probe spin dependent scattering interactions between polarized electrons and surfaces or polarized electrons and atoms. The electron-surface scattering capability can be used to determine surface structure or study surface magnetic phenomena and their dependence on temperature, composition, adsorption, etc. The electron-atom scattering capability can be used to probe spin-orbit and exchange interactions in electron scattering and to completely determine the parameters of a selected collision process.

In relatively new research directions, an electron polarization microscope consisting of special electron spin detectors and a scanning electron microscope is being used to probe magnetic structure of technologically important materials on a sub-micron scale. A scanning tunneling microscope has also been constructed to apply the phenomenon of surface-vacuum-surface electron tunneling to investigations on an atomic scale of the nucleation and growth of thin films on clean metallic and semiconductor surfaces.

As can be seen in the following sections, the Division staff has been active in publishing research papers, providing calibration services, presenting invited talks, sponsoring conferences, providing consultation services, and participating in technical and professional committees. We have also been very active in technical collaborations within NBS and with universities, industry, and other government agencies. Highlights of the past year include:

1. The new technique of scanning electron microscopy with electron polarization analysis (SEMPA) was used to make unique, unprecedented high resolution (10 nm) measurements of the magnetic microstructure of advanced magnetic recording materials, in collaboration with 3 industrial research organizations.

2. The orbiting electron energy of SURF-II was increased from 282 MeV to 300 MeV. This results in a significant gain in photon flux at the soft x-ray end of the synchrotron radiation spectrum. The improvement is a factor of 2 at 5 nm. This improvement in flux will allow an extension of calibration services to shorter wavelengths and will allow atomic/molecular, solid state, and surface physics experiments up to, and beyond, the important carbon K edge at 4.3 nm.

3. A new soft x-ray measurement program was implemented at SURF-II and the Brookhaven-NSLS in collaboration with the U. of Tennessee and ORNL. Measurements utilizing a new, state-of-the-art, soft x-ray emission spectrometer were made to study radiation damage mechanisms in fragile solid materials (the alkali halides, LiF and NaCl).

4. A new, high energy measurement capability and beamline was commissioned at SURF-II to extend our user program in surface science and ultraviolet photoemission spectroscopy to higher photon energies. The new measurement system was utilized by the NBS Surface Science Division and by a new user team from Yale U. and U. of Central Florida studying electron correlations in the simultaneous photoionization and excitation of helium, $He + h\nu \rightarrow He^{+*} + e$.

5. An updated SURF Users' Guide was completed, replacing an earlier version published 10 years ago.

6. Documentation of the far UV detector calibration service was completed and submitted for publication in a special NBS SP 250 series.

7. A new collaboration between Division staff and staff from Los Alamos, Argonne, and Daresbury was planned to enable complementary and coordinated photoionization studies to be done at the SURF-II, Brookhaven/NSLS, and Daresbury synchrotron radiation facilities.

8. Division staff are a part of a Materials Research Group (MRG) that will be funded by NSF to study surface magnetism at NSLS using the techniques of spin polarized photoemission and molecular beam epitaxy. The group consists of 11 principal investigators from 8 major laboratories representing industry, universities, and government laboratories.

9. Fifteen major visiting scientist collaborations were active in FY86: three in the Far UV Physics Group; four in the Electron Physics Group; and eight in the Photon Physics Group.

10. For the third year in a row, work in the Division is being recognized with an IR-100 award, shared jointly with colleagues from the U. of Tennessee and ORNL for the development of a soft x-ray emission spectrometer that can measure weak radiation with efficiencies 1000 to 10,000 higher than conventional spectrometers in the energy range 20 eV to 1 KeV.

FAR UV PHYSICS GROUP

The Far UV Physics Group is characterized by the development of radiometric techniques and standards for far ultraviolet radiation and by research on measurement methods utilizing far ultraviolet radiation. The NBS electron storage ring, SURF-II, is operated for radiometric research and calibrations of spectrometer systems and transfer standard detectors, and as a source of VUV/soft x-ray radiation for user-groups within NBS and outside. Additionally, off-SURF experimental research and development in radiometry is carried out, and transfer standard detectors are calibrated and supplied in the wavelength region 115-250 nm.

SURF-II Operations and Improvements (L. Hughey and J. Pollard)

The NBS Synchrotron Ultraviolet Radiation Facility (SURF-II) achieved another milestone in performance in December 1985 by reaching an operating energy of 300 MeV. The increase in the energy of the stored electron beam from 282 to 300 MeV results in a significant gain in photon flux at the soft x-ray end of the synchrotron radiation spectrum, in the wavelength region from 20 nm down to about 4 nm. The increase in photon flux density at 5 nm, for example, is about a factor of two, and useful flux from SURF-II is now available to below 4 nm (300 eV). This significant advantage allows an extension of the spectral region covered by the radiometric activities of SURF-II and allows atomic/molecular, solid state, and surface physics experiments up to and beyond the important carbon K edge at 4.3 nm.

In the past, the operating energy had been limited to 282 MeV by the magnet cooling and the radio frequency accelerating systems, both of which had been originally designed for 240 MeV. The addition of a second heat exchanger and installation of an RF system capable of twice the output power has overcome these limitations.

The new RF system has also improved beam lifetime and the beam dynamics of the circulating electron beam by stabilizing a troublesome longitudinal bunch oscillation. With the old RF system these oscillations were present at all beam currents greater than 19 mA. In initial tests, the beam was phase stable to more than 160 mA. The system will be further improved by replacing a phase-shifter and coaxial attenuator that are still not optimized. This stability opens the door to a new class of experiments at SURF-II involving the measurement of fluorescence on the picosecond time scale.

Average beam current achieved from August 1985 through June 1986 was over 85 mA. SURF-II provided beam to users 92.5% of the scheduled beam time. The scheduled user beam time is 9 hours per day, Tuesday through Friday. Mondays are used for maintenance, improvements, and continuing assessment of the machine's radiometric parameters.

SURF-II Users Program (R. Madden)

A new Users' Guide for SURF-II has been prepared and is now available. This revision was made to reflect several major improvements at the SURF-II facility. This guide replaces one written more than ten years ago and is intended to provide most of the information a new user at SURF-II will require.

The many changes that have taken place at the facility include notable improvements. These include an increase in operating energy of the electron storage ring from 240 MeV to 300 MeV and an increase in circulating electron beam current from 10 mA to over 100 mA (with a maximum of 200 mA to date). All flux output curves for the synchrotron radiation from the storage ring as well as the various spectrometers on line have been updated. While the earlier handbook described only the three beamlines which were instrumented at that time, the current handbook covers the eight beamlines in use today. The beamline descriptions include the single original spectrometer, which is still in place, as well as three new instruments of advanced design which were placed on SURF-II only in the last two years.

In addition to sections on machine description, beamline layouts, vacuum requirements, and guest scientist arrangements, the new Users' Guide has been expanded to cover characteristics of synchrotron radiation, safety requirements, listings of places to stay in the area, maps, etc.

As shown in the accompanying table, SURF-II users were active during FY86 in the areas of spectrometer calibrations, surface science, atomic and molecular physics, radiation effects in solids, and UV and soft x-ray optical physics. Those technical activities in the table that are indicated as collaborations with Radiation Physics Division staff are described in more detail in other sections of this report.

In a new thrust to reach out to potential SURF-II users, Division staff and users presented a series of five papers at a workshop sponsored by the Materials Science Advisory Committee of the Southeastern Universities Research Association (SURA). These presentations described opportunities for doing solid state research, surface science, and materials science using VUV and soft x-ray radiation at SURF-II. One of the presentations, by a U. Tennessee SURF-user, highlighted the advantages of making measurements at SURF-II in preparation for more extensive measurements at larger national facilities, in this case at the Brookhaven NSLS.

SURA is a consortium of 34 universities from the southeastern part of the country. Its Materials Science Advisory Committee is presently investigating materials research opportunities at existing synchrotron radiation facilities.

SURF-II USER ACTIVITIES

Spectrometer Calibrations

- 18 user groups involved in solar physics, astronomy, plasma diagnostics, atomic physics, and standards development.

Surface Science

- Users from NBS Center of Chemical Physics interested in photon-stimulated desorption studies of ion desorption mechanisms and energetics.

Atomic and Molecular Physics

- Users from Yale U. and U. of Central Florida interested in measuring electron correlation effects in the simultaneous photoionization and excitation of helium.

- Users from the U. of Maryland and NRL interested in developing a very high spectral resolution radiation measurement capability for molecular physics applications.

- Users from the U. of Maryland and Howard U. (with 533.06) interested in polarized fluorescence of excited molecular systems.

- Users from LANL and Argonne National Labs (with 533.06) interested in angle resolved photoelectron spectroscopy of excited molecular systems.

Solid State Studies

- Users from ORNL and the U. of Tennessee (with 533.06) interested in the electronic structure of fragile materials and layered compounds.

UV and Soft X-Ray Optics

- Users from GSFC interested in the optical properties of highly reflecting multilayer devices.

Far UV Detector Calibrations (R. L. Canfield and N. Swanson)

A new detector calibration system at SURF-II came on-line during FY 86 and is routinely producing a number of outgoing calibrations of photodiode standards in the 5-50 nm spectral region, using the photoionization of rare gases as an absolute reference standard. This system has achieved the design goals of rapid throughput and improved accuracy, resolution, and flexibility, having also been used to make preliminary gas absorption and optical properties studies.

The calibration facility features dual, toroidal grating monochromators optimized for the 3-60 nm region. This, taken together with an upgrade in the SURF-II storage ring from 284 MeV to 300 MeV orbiting electron energy, results in much greater flux levels at the soft x-ray wavelengths than available previously. Another feature that promotes greater precision and accuracy is a carousel arrangement allowing up to 5 detectors to be calibrated in a single measurement protocol.

In the 52-254 nm region transfer standards are calibrated in other Group lab facilities, referencing to the photoionization of rare gases at short wavelengths with spectral extension to the longer wave-lengths using a thermopile. A total of 21 calibrated transfer standards or recalibrations of previously supplied standards were provided for 18 outside user groups, as well as several NBS staff, serving such fields as solar physics, aeronomy, plasma diagnostics, astronomy, and solid state physics. Documentation of the NBS far ultraviolet detector calibration activity has been completed and will soon be published as an NBS Special Publication (SP 250-2).

Spectrometer Calibrations (S. Ebner and T. Hall)

The large spectrometer calibration facility at SURF-II was active for 32 weeks during FY86, during which 18 user groups conducted instrument calibrations for use in plasma diagnostics, solar physics, etc. This facility uses the calculable radiant flux from SURF-II as a radiometric standard and enables users to characterize absolute instrument response in the 4-400 nm spectral region. Users were from NASA/GSFC, North Carolina State U., Johns Hopkins U., LASP/U. of Colorado, NRL, and NBS. NASA support for this facility continues.

One of the highlights of this calibration program was the pre- and post-flight calibrations of the radiation responsivity of the Solar Ultraviolet Spectral Irradiance Monitor (SUSIM) experiment. SUSIM is a space shuttle experiment that flew for the second time in July, 1985, with one of the NRL principal investigators as astronaut payload-specialist.

Surface Science (T. Madey, R. Stockbauer, and R. Kurtz)

We have supported at SURF-II the establishment by the NBS Surface Science Division of an experimental capability to study adsorbed molecules on surfaces. These studies use several SURF-II monochromators and an ultrahigh vacuum system. Photon stimulated desorption (PSD) of ions is being studied to understand desorption mechanisms and energetics. Variable wavelength ultraviolet photoemission spectroscopy (UPS) is also utilized to characterize the surface species formed upon adsorption of the molecules on clean metal and oxide substrates. Ion desorption mechanisms for ionically and covalently bonded adsorbates are investigated.

During the past year, the beamline was upgraded with the installation of a laminar profile, ion-sketched grating and an in-situ photon monitor. The laminar profile grating greatly reduces the second order light from the monochromator. Since the PSD data are greatly affected by higher order radiation, this will greatly reduce the corrections which must be made to the data. The in situ photon monitor will allow an independent and real-time determination of the photon flux incident on the sample. This will reduce the uncertainty in PSD measurements, since the data must be normalized to the photon flux.

Several important studies were conducted last year. The first was the continuation of a study of PSD from a single crystal of TiO_2. This compound is used as a model system for the theory of Auger-stimulated desorption. It was found that ions desorb more readily from a defect surface than from the nearly perfect surface. This is contrary to what current theory predicts and shows the competition between electronic state and geometrical structure. The reduced coordination of the oxygen atom with the Ti cation gives an enhanced ion yield and shows the importance of geometry in the desorption probability.

Another study involved PSD from CO adsorbed on a Cr(110) surface. It was found that at low coverage the CO either lies flat or at a very inclined angle to the surface. At higher coverages or with coadsorption with oxygen, the CO stands upright. Presently, photon stimulated ion desorption from the inclined or upright CO is being studied.

An electron photoemission study is underway to observe chemically induced phase transitions on a single crystal VO_2. This crystal undergoes a semiconductor-metal phase transition as it is heated above room temperature. The study will determine if the transition can be induced at room temperatures by the adsorption of a molecule such as CO.

Very High Resolution Spectroscopy at SURF-II (M. Ginter and R. Madden)

The installation of a very high resolution 6.65 m normal incidence monochromator is continuing at SURF-II. Researchers from the U. of Maryland and the NRL are the principal investigators on this project with partial support from the NSF. The goal of this project is to carry out research on the dynamics of energy transfer in atoms and molecules with an energy resolution that is a factor of ten better than photometric instruments currently in service at synchrotron radiation facilities. In a collaborative effort, a similar instrument is being installed and converted to photometric studies at the KEK Photon Factory in Japan. These instruments will cover the 30-200 nm spectral range with resolving powers of 2×10^5. In addition, our instrument will provide highly polarized radiation to study atomic and molecular systems (polarization > 98% for wavelengths >60 nm).

This instrument is now installed at SURF-II. The beamline and its optics have been commissioned. Polarization studies of the collection optics have confirmed the high degree of polarization of the radiation entering the spectrometer. U. of Maryland and NRL staff intend to put the spectrometer into operation by spring, 1987. The instrument is now under vacuum and detection systems are being prepared for use. Expected NBS users of this instrument are from the Centers for Radiation Research, Basic Standards, and Chemical Physics. Outside users expressing interest in using this facility are from NRL, U. of Maryland, ORNL, Yale, Argonne, SUNY Binghamton, Ohio State, U. of Nebraska, Harvard College Observatory, Imperial College, and the Bhabha Atomic Research Center of India.

ELECTRON PHYSICS GROUP

The Electron Physics Group has ongoing research efforts in electron collision physics including electron-surface interactions, surface magnetism, electron interaction theory, electron polarization phenomena, electron-atom and electron-molecule collisions, and electron optics and instrumentation. The wide applicability of electron-based measurement technologies allows us to contribute to the solution of many diverse scientific and technological problems.

This year we have continued to increase and focus our efforts toward the study of microscopic phenomena and their influence on the macroscopic properties of surfaces. As in the recent past, a major emphasis is on magnetic phenomena and structure. We are in the process of adding a scanning Auger microprobe facility to our effort which will greatly increase our capabilities in the study of magnetic microstructure. Additionally, most of our experiments are being adapted to the use of the technique of molecular beam epitaxy to grow thin over-layer films, permitting us to study interfacial phenomena.

Electron-Atom Collision Studies (M. Kelley, J. McClelland, and B. Waclawski)

The general aim of this project has been to study electron-atom collisions under conditions where all important parameters in the collision process have been experimentally determined. These "complete" or fully specified experiments provide a stringent test of our current understanding of electron-atom collision physics. Such interactions as the exchange or the spin-orbit interaction are separately observed. Following our first work on near-threshold ionization and the optical pumping preparation of polarized sodium beams, we began a study of spin-polarized superelastic scattering. Our initial superelastic measurements were conducted using linearly polarized laser light to excite the atoms. This yielded the very surprising result that large spin-asymmetries were observed despite the fact that the excited states were not spin polarized. The explanation of this effect required an understanding of the coupling between the orbital angular momentum of the scattered electron, the orbital angular momentum of the target electron, and the target electron's spin. We also observed that the spin asymmetry depended on the relative quantum mechanical phases of the excited magnetic sublevels as prepared by the optical pumping. Work is currently underway to understand this from a theoretical point of view.

Most recently we have made measurements using circularly polarized light. In this case the atoms appear in a pure excited state - the electron spin and angular momentum (as well as the nucleus spin) have maximal orientation either parallel or anti-parallel to the incident laser. A measurement of the spin-asymmetry under these conditions gives the maximum possible information on the scattering process because pure state-to-state scattering is realized. Very dramatic effects occur such as a large difference in the behavior between scattering to the left and scattering to the right, and a very rapid change of the scattering asymmetry from positive to negative near a scattering angle of -30° for electrons with 9 eV incident energy.

Our current efforts consist of formulating a theoretical basis for understanding the above data and making measurements at other incident electron energies and scattering angles to identify systematic trends and additional effects. Future plans call for beginning measurements on spin-polarized elastic electron scattering.

Scanning Electron Microscopy with Polarization Analysis (SEMPA)
(R. Celotta and J. Unguris)

Scanning Electron Microscopy with Polarization Analysis (SEMPA) is the name we have given to a technique we have developed to explore sub-micron magnetic domain structures. When an electron beam is incident on a magnetic material, spin-polarized secondary electrons are emitted. The electron spin polarization of these electrons is simply proportional to the spin polarization of the valence electrons in the solid. Therefore, a measurement of the polarization of the secondary electrons yields a direct measurement of the magnetization in the region of the sample probed by the incident electron beam. We have added electron spin-polarization analyzers to a scanning electron microscope in order to measure the magnetic structures present with high spatial resolution. We not only obtain the usual topographic map of a material, but also simultaneously and independently image the magnetic microstructure of the surface. The spatial resolution of the two images is the same, approximately 10 nm. Because SEMPA is a new technique, much of the early work has involved developing and perfecting the instrumentation and performing a series of exploratory experiments to test capabilities of the method. This involved the development of a new kind of electron spin-polarization analyzer based on the spin-orbit interaction in the scattering of 150 eV electrons from an evaporated Au film. This detector is much more compact and simpler to use than previous detectors.

So far we have successfully imaged magnetic microstructures in the following materials: (1) Fe-3% Si single crystals; (2) Permalloy thin films; (3) Permalloy thin-film recording heads (provided by Control Data Corporation); (4) CoNi sputtered films (provided by Kodak); and (5) various Fe-based metglasses (provided by the Naval Surface Weapons Center and Allied Chemical). Work in progress involves the study of magnetic microstructure in Co single crystals and in evaporated Fe films. We are planning to use SEMPA to investigate a variety of micromagnetics systems in great detail. Of primary scientific interest are two-dimensional magnetism in thin films and surfaces, magnetic structure within domain walls, and the magnetic structure of sub-micron devices. These are reflected in systems with immediate technological implications such as magnetic recording media, thin film memory devices, magnetic domain dynamics, new fine-grained magnetics for electrical motors, and the magnetism of layered materials.

Finally, in order to meet the demand for these types of measurements, we are in the process of adapting another electron microscope for spin-polarization analysis. This microscope will include a scanning Auger microprobe and will therefore be able to give us a map of the chemical composition of the surface along with the topographic and magnetic images.

We are working to build joint research efforts with industry, other government laboratories, and universities. We have received a multitude of samples from major corporations interested in exploring the applicability of this new technique to outstanding scientific and technological problems of concern. We are in the process of establishing research agreements with a number of industrial/university/government laboratories to pursue specific illustrative research problems using this new technique. We expect these collaborative efforts will prove to be scientifically fruitful, intellectually stimulating, and mutually beneficial.

This is a collaboration project with staff from the Micro and Optical Metrology Group of the NBS Center for Manufacturing Engineering.

Scanning Tunneling Microscopy (D. Pierce, R. Dragoset, R. Young, and S. Mielczarek)

In a small pilot program, we are operating a scanning tunneling microscope to better our understanding of the nucleation and growth of thin films on clean metallic and semiconductor surfaces. We have successfully operated the instrument in air, scanning gold and pyrolytic graphite surfaces, and we have measured the regular structure of a mechanically fabricated diffraction grating. While working in a high vacuum environment, we studied the result of the diamond-turning process used to fabricate extremely smooth mirrors. We have now completed the installation of this system in a standard ultra-high vacuum surface analysis chamber which allows, in addition to scanning tunneling microscopy, LEED, Auger spectroscopy, ion-sputtering, and sample installation, heating, cooling, and cleaning. The control of sample cleanliness and preparation available to us in this new system should permit us to observe surface topography with atomic resolution.

Our primary experimental interest is the characterization of thin-film growth structures. Our initial plans include obtaining atomic resolution on a single crystal surface, e.g. Si(111), and observing surface changes after sub-monolayer deposition of an evaporant. We will attempt to perform evaporation in situ in order to scan the same area of the surface before and after evaporation. We hope to correlate changes in surface structure after evaporation with the character of the surface before deposition (e.g. defects).

Inverse Photoemission (D. Pierce, L. Klebanoff, and R. Jones)

Our work on the scattering of spin-polarized electrons from surfaces continues with a high level of activity. By using our polarized electron gun to observe the effects of the exchange interaction, we are able to sense the local net alignment of spins in the surface of a ferromagnet. The short mean free paths for elastically scattered electrons make this technique extremely surface sensitive, unlike neutron scattering.

Although in its infancy, inverse UV-photoemission has emerged as a very useful new method of gaining an understanding of the electronic structure of surfaces in general, and of ferromagnetic surfaces in particular. When it is used with the complementary method of photoemission spectroscopy, it is possible to gain a complete picture of the electronic structure of surfaces.

The direct process, i.e., spin-polarized, angle-resolved, and energy-resolved photoemission, is normally observed using a high intensity synchrotron radiation source, a UV monochromator, an electron energy analyzer, and a spin polarization detector. We have demonstrated that it is possible to do the inverse experiment, where spin-polarized electrons at a specific energy and angle of incidence are scattered from a target and the UV photons at a selected wavelength are detected. With a nickel (110) single crystal target, we demonstrated that only minority spin electrons are absorbed into unfilled d-bands and give rise to UV photons. This type of experiment allows one to observe the spin-polarized unfilled states near the Fermi level. By varying the angle of incidence we also measured the dispersion of these bands.

We have recently completed an investigation of the clean Ni(001) surface and the c(2x2) adsorption systems, O/Ni(001) and S/Ni(001). For clean Ni(001), we found a minority-spin character for the unoccupied 3d band, but an essentailly non-magnetic character for the Ni 4sp band. These spin-dependent results confirm previous spectral assignments made for Ni(001). No spin splitting of the 4sp band was found for Ni(001), in contrast to the splitting observed for Ni(110). No spin dependence of the Ni(001) image potential surface state was found. Our investigations of Ni(001) chemisorption yielded surprising results. No evidence was found for a c(2x2) oxygen-induced antibonding state at the surface Brillouin zone center, Γ. This finding is in direct contradiction with the published experiments of Scheidt and theoretical predictions. The chemisorbed oxygen does not significantly affect the spin dependence, and hence the intrinsic magnetization, of the observed minority-spin 3d spectral peak.

Chemisorbed sulfur produces qualitatively different results. The presence of a c(2x2) sulfur overlayer produces a small intensity enhancement at the Ni 3d inverse photoemission peak, and reduces the observed spin dependence of the peak by four-fold. These variations suggest the possible existence of a sulfur-induced unoccupied state of majority spin character just above the Fermi level at Γ. Such a state would play a central role in the mechanism by which sulfur destroys surface magnetism.

Electron Transport Theory (D. Penn)

Three theoretical topics were explored during this past year. Recent experiments using polarized electron beams and spin-polarized detection have stimulated a detailed theoretical analysis of the spin-dependent scattering process. Our conclusion is that free electron-like Stoner excitations contribute predominantly to the scattering process. The free-electron Stoner excitation is an electron-hole pair excitation consisting of a d-hole of given spin and an electron in a free electron-like state of opposite spin. This differs from the usual Stoner excitation in which the electron is in a d-state. The model used demonstrated that the electron-hole pair excitations which contribute significantly to exchange scattering have free electron-like final states as opposed to those of the usual d-character. Thus, creation of a free-electron Stoner excitation is far more likely than the usual type of Stoner excitation.

Despite the importance of the inelastic mean free path, experimental values for a given material are generally available only in a limited energy range and the measured values are subject to relatively large uncertainties. On the theoretical side the situation is no better. With the exception of free electron materials such as $A\ell$, the mean free path has not been calculated from first principles. The primary missing ingredient is the dielectric response function which depends on the energy and momentum lost by an electron in a collision. Thus, existing calculations are semi-phenomenological and, because of experimental problems, it is difficult to assess how well the theories actually work.

During the past year the mean free path has been calculated based on a model dielectric function whose form is motivated by the use of the statistical approximation. In the limit that the momentum transfer is zero, the model dielectric function is set equal to the measured optical dielectric function which has been measured for a wide variety of materials in synchrotron radiation studies. The results are calculated values of the mean free path for electron energies in the range of 5 eV to 10 keV for Cu, Ag, and Au.

Also developed was a theoretical formulation of the screening problem at an interface. This calculation, from the start, has the main features of the geometrical situation built in. The focus is on the influence of the geometry on the effective Coulomb interaction between two charged particles. This geometrical influence generally enters on two levels. Provided one properly includes the presence of an interface (global level), one can go very far in using a bulk response function. The local geometrical information then enters as a correction in most cases (in some situations it is crucial) to the calculation based on the bulk response function. The result is a completely general expression for the Coulomb interaction between two test particles in the presence of an interface in which the local and global effects of the geometry are separated. The potential is given for the two test-particles outside, inside, or on either side of the interface, and appropriate limits are investigated.

Polarized Photoemission Studies of Magnetic Systems (R. Celotta and D. Pierce)

Last year we mentioned a new effort in collaboration with AT&T Bell Laboratories and Brookhaven National Laboratory to employ spin-polarized, angle-resolved photoemission to study surface magnetism. This pilot effort has been greatly expanded in scope by the addition of a large number of prominent collaborators to form a Materials Research Group (MRG). The NSF-supported MRG consists of eleven principal investigators from the following institutions: AT&T Bell Labs, NSLS-Brookhaven National Laboratory, Argonne National Laboratory, Northwestern U., Rice U., U. of Texas at Austin, Naval Research Laboratory, U. of California at Irvine, and our own Group at NBS. The focus of the effort will be to study both bulk materials and epitaxial ferromagnetic mono-, bi-, tri- and multi-layer materials. Investigations will include ground state magnetic properties, testing local density theory predictions, surface magnetic critical phenomena, spin-dependent photo-excitation, and energy- and wave-vector- resolved electron spectroscopy. Because of the increasing importance of interfaces and multi-layered structures, the experimental station will include a molecular beam epitaxy apparatus for fabricating unique magnetic multi-layered structures. A component of this research will be aimed at improving the photon flux available from the U-5 beam port on the NSLS UV storage ring. Our MRG has been designated as an insertion device team and will be installing a new undulator to provide a greatly enhanced photon flux for use in spin-polarized photoemission experiments.

This effort in understanding exotic magnetic structures will complement our effort in magnetic microstructure (SEMPA) and physical and electronic microstructure (STM) and greatly enhance our ability to understand the macroscopic physical properties of matter through study of their microscopic structure.

PHOTON PHYSICS GROUP

The Photon Physics Group investigates the interaction of electromagnetic fields on atoms and molecules in various environments in support of radiation measurements and standards programs important to NBS and the outside technical community. This work includes theoretical and experimental studies on the electronic structure of atomic and molecular systems in field free environments and in strong external fields. The group has specialized in ionization phenomena and in nonlinear or multiphoton laser-atom interactions. Studies are currently focused on molecular excitation dynamics, shell contraction in atoms, multiphoton transitions, atoms in high electric and magnetic fields, and the structure of highly excited atoms. Collaborative work is directed toward ultrasensitive analysis through resonant multiphoton ionization, the measurement of picosecond VUV pulses by nonlinear cross correlation techniques, the development of a laser plasma VUV source, and the identification of highly excited atomic states suitable for a soft x-ray laser. For many of the activities, synchrotron radiation from NBS-SURF-II is used as a source of tunable vacuum ultraviolet and soft x-ray radiation.

Ultrasensitive Trace Analysis (T. Lucatorto, C. Clark, R. Bonanno, and C. Johnson)

This is a collaborative effort with the Mass Spectrometry Group in the NBS Center for Analytical Chemistry having the goal of developing a resonance ionization mass spectrometric (RIMS) capability with sub part-per-billion isotopic abundance sensitivity. Present thermal ionization mass spectrometers have an ultimate isotopic abundance sensitivity of about one part in 10^7. By putting isotopic selectivity into the resonance ionization step, we hope to improve the overall sensitivity by three to five orders of magnitude. Since the optical isotope shift for most elements is in the range of 0.1 to 5 GHz, this selectivity can only be achieved by a high resolution laser system used in a Doppler-free mode.

We have completed development on a high resolution pulsed dye amplifier having a bandwidth of about 150 MHz and output energy of 25 mJ. The new system was used to make the first measurements of the ^{9}Be: ^{10}Be isotope shifts in several two-photon transitions ($2s^2\ ^1S \rightarrow 2s5s\ ^1S$, $2s6s\ ^1S$, $2s7s\ ^1S$, $2s5d\ ^1D$, $2s6d\ ^1D$). The isotopic selectivity observed in the ionization process was greater than 1:3000, but this cannot at the present time be translated into a related enhanced abundance sensitivity ($\sim$ 1: 10^{10}) because of a limitation of the overall sensitivity ($\sim$1:10^7) due to the present low efficiency of sample utilization. To overcome this problem, we have recently begun studies on pulsed laser desorption as a method of atomization matched to the duty cycle of the ionization laser. Initial results are very promising.

Two new-postdoc projects related to this work are a krypton ion-beam isotope separation experiment and an experiment on laser-induced collisional ionization.

The krypton work actually has two goals: in the short term the radiation from the charge exchange and laser excitation section of a recirculating ion beam will be investigated as a potential VUV standard source; the long term calls for the efficient recirculation of laser-excited, laser-ionized krypton in a mass spectrometer storage ring for isotopic abundance analysis in the sub-part-per-trillion range. This work has been developed into a collaboration with the Radiometric Physics Division.

Studies of laser-induced collisional ionization are being done in a collaborative effort with the U. of Maryland. The initial experiment is to measure the associative ionization process, $Na^*(3p) + Na + h\nu \rightarrow Na_2^+ + e$, using, for the first time, a cw laser to control the process. Such measurements should prove to be much more reliable and accurate than previous measurements made with pulsed lasers, and should yield knowledge on charge exchange rates that could have deleterious effects on the selectivity of several resonance ionization mass separation schemes.

<u>Photoabsorption of Laser-Ionized Species</u> (T. Lucatorto, C. Clark, J. M. Bridges, C. Cromer, and B. Sonntag)

Our group has a unique capability to measure the VUV photoabsorption (between 8 nm and 65 nm) of laser-excited and laser-ionized atoms. The instrumentation includes a state-of-the-art VUV spectrometer with a 1024 channel photoelectric detector, a 20 ns pulsed VUV source, and several MW-scale, pulsed, tunable dye lasers. During this year we have added a high temperature (up to 2500 C) heat-pipe oven and a mode-locked Nd:YAG laser capable of powers of 0.3 GW for durations as short as 30 ps. The new heat-pipe oven will allow us to study a large number of the transition and rare earth metals, and the new laser will enable us to produce sub-ns VUV pulses.

Photoabsorption studies of laser-excited and laser-ionized atoms have uncovered the dramatic effects of relatively small changes in electron screening on orbital collapse. In collaboration with a visiting scientist from the University of Hamburg, we have completed measurements of the 3p-photoabsorption of the calcium ground state (Ca: $4s^2\ ^1S_0$), the lowest excited states (Ca: $4s4p\ ^3P_{0,1,2}$), and the ion ground state (Ca^+: $4s\ ^2S_{1/2}$). The absorption spectrum of the excited state shows a marked qualitative difference from the absorption spectrum of both the neutral ground state and the ion. An explanation for these changes is being sought by several theorists (C.W. Clark and A.W. Weiss at NBS and a visiting scientist from Royal Holloway College, London).

Our latest experimental work has been the 3p-photoabsorption of the manganese ground state (Mn: $3d^5 4s^2\ ^6S$), the excited states (Mn: $3d^5 4s4p\ ^8P$), and the ion (Mn^+: $3d^5 4s\ ^7S$). The objective of this research is to explain why the 3p-photoabsorption in chromium (Cr: $3d^5 4s\ ^7S$), which displays a well-developed Rydberg series, differs so much from the analogous photoabsorption in manganese (Mn: $3d^5 4s^2\ ^6S$), which has a single strong broad resonance and several much weaker features. The photoabsorption results of the manganese ion (Mn^+: $3d^5 4s\ ^7S$ which is isoelectronic to Cr: $3d^5 4s\ ^7S$) show structure which is qualitatively unlike both the chromium and neutral manganese results. Obviously the difference in screening between the Mn^+ and Cr has a crucial influence on the structure of the $3d^5$- and $3d^6$-based configurations which play a central role the 3p-photoabsorption spectrum. We are pursuing a theoretical explanation of the effect.

Another aspect of this program, in collaboration with the Atomic and Plasma Radiation Division, includes the development of laser-produced plasmas as intense, pulsed VUV sources. Our initial work was aimed at providing relative spectral irradiance measurements for several target materials of practical interest (Al, Cu, Sn, Sm, Yb, W, and Pb). We have recently begun to make absolute spectral irradiance measurements on a spectrometer calibrated at SURF-II in preparation for an intercomparison with the PTB group in Germany who are using the BESSY synchrotron as the calibration standard for their irradiance measurements. The goals of the PTB-NBS collaboration are to develop the laser-produced plasma as a standard source and to develop criteria for the laser parameters to ensure maximum reproducibility and reliability. An especially interesting task will be the comparison of results obtained with the NBS Q-switched ruby laser, the PTB Q-switched Nd:YAG laser, and the new NBS mode-locked Nd-YAG system. The Q-switched systems produce pulses with a large amount of time structure which varies considerably from shot to shot, while the mode-locked system produces almost transform-limited pulses. The question which will be addressed is the importance of short term temporal fluctuations in the non-linear process generating the VUV plasma emission.

<u>Angle Resolved Photoelectron Spectroscopy (ARPES)</u> (A. Parr and J. Hardis)

The high resolution ARPES experiment has been reinstalled on the two-meter normal incidence beamline at SURF-II. The instrument has been outfitted with position sensitive detectors, new internal electrostatic shielding, a movable gas jet, and enhanced pumping. The instrument utilizes the high spectral resolution made possible by the small beam size at SURF-II. With this capability we will make high resolution studies of selected molecular systems to enhance our understanding of molecular photoionization dynamics.

A new multi-tasking computer system has been installed to run the experiment and allows for improved data acquisition, real-time display, and printing. This will improve cumulative data capability by as much as a factor of 2. Additionally, an improved data reduction capability using a micro-Vax-II has been implemented and will improve the quality and speed of analysis significantly.

Polarized Fluorescence Studies (D. Ederer)

A series of studies has been carried out at SURF-II using the polarization of the synchrotron radiation beam as a probe of molecular autoionization. These studies showed that the polarization of the fluorescence from excited states is a direct probe of the photoionization dynamics and of the asymmetry signatures of autoionization resonances. The original apparatus has been modified, and a new optical bench has been constructed to more fully exploit the high flux capabilities at SURF-II. These modifications improve our measurement capability in the following ways:

a) It is possible to study polarized fluorescence from molecular gases;

b) Electric fields can be applied to study threshold shifts and Stark effects;

c) Wavelength-dispersed fluorescence can be measured;

d) A time-of-flight mass spectrometer has been added to detect ionic fragmentation products that result when a molecule interacts with a photon; this module will be especially useful for use with the pump-probe experiments that are planned.

First measurements have been made on the alignment of O_2^+ and a paper on the subject is currently in preparation. We are presently seeking support for experiments to derive the heat of formation of important atmospheric molecular species by measuring the fluorescence of dissociative products. This work is a collaboration with the U. of Maryland and Howard U.

Laser Prepared States (Pump-Probe Experiments) (D. Ederer and A. Parr)

A new class of experiments are being planned which will utilize both lasers and synchrotron radiation to ionize specially-prepared excited atomic and molecular states. We have purchased a mode-locked Nd:YAG laser for this application, but still require a doubler and a Q switch to complete the laser system. The hardware for the polarized fluorescence experiment will be adapted to these experiments, as will be the high resolution photoelectron spectrometer.

In the interim it has been possible to continue a collaborative research program at LURE in Orsay, France. This experiment consists of a toroidal grating monochromator connected to the ACO storage ring at Orsay, France. A ring dye laser, stabilized to 20 MHz bandwidth, was used to pump ground state atoms to the excited states in the atomic vapor. The output of the monochromator and the laser intersect at right angles in the sensitive volume of the electron spectrometer. An effusive beam of metal vapor intersects these photon beams, and the photoelectrons produced in the interaction zone are detected in the electron energy analyzer. This collaborative effort has achieved several major goals:

a) We have published a Physical Review Letter reporting the oscillator strength of autoionizing resonances in sodium produced by transitions of the type $2p^6 3p \rightarrow 2p^5(^2P_{3/2,1/2})3s3p(^1,^3P)$.

b) We have completed the measurements of the partial photoionization cross section from the 5d metastable state in barium vapor and have reported the partial 5d cross section over the energy range 15-150 eV.

c) We have completed a book chapter for advances in Atomic and Molecular Physics entitled "Photoionization and Collisional Ionization of Laser Excited Atoms Using Synchrotron Radiation." In addition to scientists from LURE, researchers from the Laboratory Aime Cotton, the Service de Physique des Atoms et des Surfaces, CEN/Saclay, and SUNY-Stony Brook are also involved in this work.

<u>Soft X-Ray Emission Spectroscopy Using Synchrotron Light Excitation (D. Ederer and T. Callcott)</u>

In a collaborative project between NBS, the U. of Tennessee, and the ORNL, a new soft x-ray emission spectrometer was installed at NBS-SURF-II to study radiation damage mechanisms in fragile solid materials, such as the alkali halides (LiF, NaCl).

The soft x-ray spectrometer is unique. It is specially designed to measure very low intensity radiation, with efficiencies 1000 to 10,000 higher than conventional spectrometers. This great improvement permits measurements to be made with weaker sources, and/or with better spatial and spectral resolution, and/or in less time (minutes instead of days). Thus, when used to measure x-ray fluorescence from irradiated samples, it will permit unprecedented measurements on low level impurities and damage in solids, or on some time-dependent processes on surfaces.

The fluorescence spectra provide important information about the electronic states of all the light elements ($Z<30$). These elements are abundant and technologically important. The measurements can be used to study the properties of alloys, material impurities, clusters, surface layers, organics, and other fragile materials. The initial studies at SURF-II were on systems of interest to materials scientists, such as the alkali halides which are commonly used as UV excimer laser windows.

After a productive year at SURF-II, the instrumentation was moved to the NSLS facility at Brookhaven in March, 1986, where the full wavelength range of the instrument, 50 nm to 1.2 nm (20 eV to 1 KeV), could be exploited. At NSLS we are now studying: the electronic structure of dilute aluminum-magnesium and aluminum-lithium alloys, important as an electrolyte in advanced batteries; bonding in alkali halides and layered compounds, to obtain a better understanding of surface layers; and thin films of aluminum implanted with rare gas atoms, to try to understand the physics of the band structure of the solid rare gases. In this work, we will be entering into new collaborations with scientists from the U. of Utah, the U. of Hawaii, and the U. of Connecticut. Based on the performance of the instrument and the preliminary results obtained so far, we have proposed additional studies of boundaries and interfaces in silicon compounds, doped silicon crystals, and other systems of importance in the fabrication of semiconductor devices. Another area that can be explored with this measurement capability is the emission spectra of solid inert gases, their alloys, and impurities embedded in the rare gas matrix.

The uniqueness of these developments has attracted considerable attention, and the soft x-ray measurement capability has been recognized by a 1986 IR-100 award from Research and Development magazine. The award was granted jointly to NBS, ORNL, and the U. of Tennessee for developing a soft x-ray emission spectrometer that can measure weak x-ray emission spectra with efficiencies 1000 to 10,000 higher than conventional spectrometers in the energy range 20 eV to 1 KeV.

Development of a Measurement Program to Use the Time Structure of the Electron Beam at SURF (D. Ederer, R. Madden, and L. Hughey)

We are planning a measurement program that makes use of the time structure of the radiation beam at SURF-II. Many important technical phenomena take place on a time scale between 10^{-9} and 10^{-13} seconds. For example, typical chemical reactions and molecular vibration times are in this time domain. In fact there is a whole new scientific research area devoted to studying phenomena occurring on the picosecond time scale. Synchrotron radiation from SURF-II is a source of pulsed (1 ns) VUV radiation that allows excitation in a "gentle" enough way that chemical reactions can be easily induced. Once this sample of excited molecules is produced, it can be synchronously probed by a laser locked to the storage ring radio frequency.

The first step in this program is to study the SURF-II electron bunch profile and its stability. To carry out this objective we have ordered a laser mode-locked to the ring frequency. During the coming year, we expect to determine the dynamics of the beam to understand what time resolution can be achieved. We are going to try to use alkali-halide excitons as the time correlator to relate the time history of the synchrotron pulse to the laser pulse.

We have submitted a proposal to the Air Force Office of Scientific Research on this topic, because we believe the technique could have important consequences for studying all types of pulsed VUV sources. We have established a cooperation with the U. of California at Berkeley and with Bell Laboratories to achieve some of these measurement goals. This work will be performed also in collaboration with staff from the Far UV Physics Group.

Electric Field Effects (E. Saloman and D. Kelleher)

This program studies the effect of electric fields on the absorption cross sections and autoionization rates of atoms and molecules. While awaiting the availability of the U. of Maryland/NRL high resolution spectrometer at SURF-II, we have continued our study of the effect of electric fields on autoionizing Ba states using multi-color, multi-photon laser excitation. Three dye lasers are used to reach odd parity states, and two dye lasers are used to reach even parity states. We have measured the Stark manifold of the $5d_{3/2}$ 8ℓ autoionizing states in Ba. Due to the non-spherical 5d ion core, the manifold is more complex than for similar 6s $n\ell$ bound states. Calculations of the Stark manifold in jK coupling are in good agreement with the experimental observations for both polarizations. We are currently planning an experiment to study the effects on the autoionization rates of coupling the autoionizing state to an unpopulated bound state.

This work is a collaboration with the Atomic and Plasma Radiation Division.

X-Ray Attenuation Cross Sections (E. Saloman and M. Berger)

The NBS data base of experimental attenuation coefficients (total absorption cross sections) was compared to cross sections obtained using two widely used sets of absorption cross section values: the semi-empirical set of recommended values produced by Henke et al. and a theoretical set of recommended values calculated by Scofield (and extended at our request down to 0.1 keV). This comparison was carried out, in both tabular and graphical form, over the energy range 0.1-100 keV. We evaluated whether Scofield's calculation should be subject to a renormalization from a Hartree-Slater to a Hartree-Fock atomic model and determined that the experimental data tend to argue against such renormalization. A bibliography of the NBS data base has been produced in conjunction with this comparison. The results of this work are due to appear as NBS Internal Reports.

We are now evaluating the possibility of calculating these cross sections ourselves using state-of-the-art relativistic wave function codes. This work is a collaboration with the Ionizing Radiation Division and the Atomic and Plasma Radiation Division.

Atomic and Molecular Theory (C. Clark)

Theoretical work in the Photon Physics Group deals primarily with atomic absorption in the far ultraviolet/soft x-ray region, and with multiphoton processes. The main focus of this work is upon multiply-excited states. Such states often make dominant contributions to these processes, and their basic physics is in many respects still poorly understood.

Ab initio calculations and analysis of data on photoabsorption by Ca, Ca^+, Cr, Mn, and Mn^+ in the 3p excitation region (~50 eV), are being carried out in conjunction with the experimental work of the group.

Studies of multiphoton processes in the past year have been concerned with the excitation of doubly-excited states of alkaline earth atoms, particularly Be and Mg. These states are of direct interest to the group's ultrasensitive trace analysis effort, but they are also of interest as relatively simple prototypes of multiply-excited states. During the year, an analysis of the Mg $3p^2\ {}^1S$ autoionizing state was completed; this was a natural extension of the work done previously on the analogous $2p^2\ {}^1S$ state of Be. Current work on Be is concerned with the ${}^1D$ Rydberg series in the discrete spectral region, which interacts strongly with the $2p^2\ {}^1D$ state. The ${}^{10}Be$:${}^9Be$ isotope shifts in this series have been shown to be very sensitive to the degree of configuration interaction, and an experimental program to measure them is being carried out in collaboration with the NBS Center for Analytical Chemistry.

Other work on multiphoton processes has investigated the possibility of observing two-photon absorption at 18.2 nm, using the soft x-ray laser at the Princeton Plasma Physics Laboratory. Several promising candidate experiments have been identified. A new initiative to convert large photoionization computer codes to calculate two-photon absorption processes in complex atoms has been started, in collaboration with a visiting scientist from Royal Holloway and Bedford New College of the U. of London (England).

A review of atomic negative ion resonances is underway in collaboration with the Australian National U.. This has resulted in some new classification schemes for these resonances, which are thought to indicate more accurately the nature of electron correlations than previous schemes have done. It is anticipated that a comprehensive review article will be completed late in 1986.

Studies of the role of orbital term dependence and electron correlation in core-excited states for complex atoms have continued, with attention to d-shell excitation of atoms in the rare-earth transition region (Cs through Ce). The effects of term dependence in excited f states have been found to be more extensive than was thought previously. Most other work in this field has concentrated on the role of the dipole exchange interaction; in configurations such as p^5d and d^9f, this interaction is strongly repulsive in the optically favored ($^1P^\circ$) channel, and it causes the excited orbital to lie much further away from the open-shell core than would be predicted in the standard average-of-configuration approximation. This effect is responsible for the placement of most of the photoabsorption oscillator strength in the continuous, rather than the discrete, portion of the atomic spectrum.

Our work has shown that other interactions can also have such an effect. In the d^9f configuration, for example, the direct quadrupole and exchange quadrupole interactions produce potential barriers in the $^1G^\circ$ and $^1F^\circ$ channels respectively. Similar effects occur in the p^5f and sf configurations. Although these states cannot be excited by photoabsorption because of dipole selection rules, they do figure prominently in electron-impact excitation. Analysis of electron energy loss data, done in collaboration with groups from the U. of Innsbruck (Austria) and York (England), has identified some of these non-dipole excitations. We believe that a comprehensive study of excitation channels in this energy region will contribute to the understanding of those which are specifically relevant to photoabsorption. In particular, observation of similar phenomena in dipole and non-dipole allowed channels may resolve the issue of whether the "giant resonances" in atomic photoabsorption are due to collective oscillations of an electron shell.

SPONSORED WORKSHOPS, CONFERENCES, AND SYMPOSIA

Division 533, Radiation Physics

C.W. Clark organized a Symposium on Physics of X-ray Lasers, 1986 Annual Meeting of the Optical Society of America.

D.T. Pierce was Vice Chairman of the Gordon Conference on Electron Spectroscopy, Wolfeboro, NH, July 14-18, 1986.

INVITED TALKS

Division 533, Radiation Physics

1. Bonanno, R.E., "Ultrasensitive Laser Isotope Analysis of Krypton in an Ion Storage Ring," Lawrence Livermore Laboratory, Livermore, CA, January 29, 1986.

2. Bonanno, R.E., "Multiphoton Excitation of Autoionizing States of Magnesium," Atom Sciences and Oak Ridge National Laboratory, Oak Ridge, TN, February 26, 1986.

3. Bonanno, R.E., "Multiphoton Excitation of Autoionizing Stages of Magnesium," Lawrence Livermore National Laboratory, Livermore, CA, April 9, 1986.

4. Bonanno, R.E., "Resonance Ionization Mass Spectrometry: Applications in Atomic Physics and Analytical Chemistry," Department of Chemistry, William Paterson College, Wayne, NJ, April 22, 1985.

5. Bonanno, R.E., "Ultrasensitive Laser Isotope Analysis of Krypton in an Ion Storage Ring," Resonance Ionization Spectroscopy Conference, Swansea, Wales, September 9, 1986.

6. Celotta, R.J., "New Techniques in Microscopy: Scanning Tunneling and Polarized Electron Microscopy," Pittsburgh Conference on Analytical Chemistry and Applied Spectroscopy, Atlantic City, March 10-14, 1986, NJ.

7. Celotta, R.J., "Viewing Surface Magnetism," Research Advisory Committee Staff Research Seminar Series on Magnetism, NBS, January 17, 1986.

8. Celotta, R.J., "New Methods of Electron Microscopy," Colloquium, Joint Institute for Laboratory Astrophysics, Boulder, CO, April 21, 1986.

9. Celotta, R.J., "New Techniques in Microscopy: Scanning Tunneling and Polarized Electrons," Spring Symposium of the New England Society for Electron Microscopy, Woods Hole, MA, May 10, 1986.

10. Celotta, R.J., "Surface Measurement by Electron Polarization and Scanning Tunneling Microscopy," Vacuum '86 Processing Technology, Nashua, NH, June 9, 1986.

11. Celotta, R.J., "Electron Polarization Microscopy and Scanning Tunneling Microscopy: New Ways to Image Surfaces," Joint Meeting of American Vacuum Society and IEEE Magnetics Society, Rochester, NY, June 12, 1986.

12. Clark, C.W., "Excited Atoms in Electric and Magnetic Fields," Chemical Physics Seminar, University of Maryland, College Park, MD, October 2, 1985.

13. Clark, C.W., "Autodetaching States of Negative Ions," First International Conference on Laser Science, Dallas, TX, November 18, 1985.

14. Clark, C.W., "Rydberg States in Electric and Magnetic Fields," Physics Colloquium, University of Delaware, Newark, DE, December 4, 1985.

15. Clark, C.W., "Highly Excited Atoms in Electric and Magnetic Fields," Australian National University, Canberra, Australia, January 23, 1986.

16. Clark, C.W., "Autodetaching States of Negative Ions," University of Tasmania, Hobart, Tasmania, Australia, January 29, 1986.

17. Clark, C.W., "Multiphoton Excitation of Autoionizing States," Workshop on Multiphoton Ionization of Atoms by Strong Fields, University of Paris, Orsay, France, April 29, 1986.

18. Clark, C.W., "Doubly-Excited States of Negative Ions and Atoms," Mathematics Colloquium, Royal Holloway and Bedford New College, University of London, Egham, Surrey, England, June 13, 1986.

19. Clark, C.W., "Giant Resonances in the Transition Regions of the Periodic Table," NATO Advanced Study Institute on Giant Resonances in Atoms, Molecules, and Solids, Les Houches, France, June 18, 1986.

20. Ederer, D.L., "Photoionization from Excited States: A Technique to Understand Atomic Correlations," Advanced Light Source (ALS) Workshop, Berkeley, CA, November 13, 1985.

21. Ederer, D.L., "Synchrotron Radiation as a Tool to Aid the Study of Atomic Collisions," Advanced Light Source (ALS) Workshop, Berkeley, CA, November 14, 1985.

22. Ederer, D.L. "Autoionizing Resonances: Peaks, Valleys, and Correlation," Southeastern Section of the American Physical Society, Athens, GA, December 2-3, 1985.

23. Ederer, D.L., "Autoionizing Resonances: Peaks, Valleys, and Correlation," University of Central Florida, Orlando, FL, April 24, 1986.

24. Ederer, D.L., "Laser-Synchrotron Pulse-Probe Experiments," Southeastern Universities Research Association (SURA), Synchrotron Radiation Workshop, Atlanta, GA, May 12-16, 1986.

25. Hardis, J.H., "Photoionization of H_2," Center for Basic Standards, NBS Colloquium, April 23, 1986.

26. Johnson, B.C., "Transition Probability of the Al II 2669 Å Intersystem Line," Goddard Space Flight Center, Greenbelt, MD, January 13, 1986.

27. Johnson, B.C., "Experimental Studies of Laser-Induced Collisions," University of Nevada, Reno, NV, June 24, 1986.

28. Kelley, M.H., "Spin Dependence in Scattering of Spin-Polarized Electrons from Optically Pumped Sodium Atoms," Annual Meeting of the American Physical Society, Division of Atomic, Molecular, and Optical Physics, Eugene, Oregon, June 20, 1986.

29. Klebanoff, L.E., "Photoelectron Spectroscopy Studies of Cr(001) Surface Magnetism," International Workshop on the Magnetic Properties of Low Dimensional Systems, Taxco, Mexico, January 7, 1986.

30. Lucatorto, T.B., "Transient State Spectroscopy in the VUV: Instrumentation and Applications," Princeton University, Princeton, NJ, December 10, 1985.

31. Lucatorto, T.B., "Observation of Conventionally Inaccessible Atomic Continua," University of Virginia, Charlottesville, VA, March 26, 1986.

32. Lucatorto, T.B., "The Photoionization of Excited States and Ions Using Many Photon and Multiphoton Techniques," University of Toronto, Canada, April 8, 1986.

33. Lucatorto, T.B., "High-Resolution Laser Techniques in Resonance Ionization Mass Spectroscopy," Department of Energy Workshop, Seattle, WA, April 29, 1986.

34. Madden, R.P., "SURF-II, Programs and Opportunities," Synchrotron Radiation Facilities Workshop, Brookhaven National Laboratory, Upton, NY, October 17, 1985.

35. Madden, R.P., "SURF-II Beamline for VUV and X-Ray Research Related to Materials Science," Southeastern University Research Association (SURA), Synchrotron Radiation Workshop, Atlanta, GA, May 12-16, 1986.

36. McClelland, J.J., "Spin Polarized Superelastic Scattering from Sodium," Joint Institute of Laboratory Astrophysics, Boulder, CO, October 1986.

37. Ott, W.R., "NBS-SURF II: Characteristics and Opportunities for Research," Southeastern Universities Research Association (SURA), Synchrotron Radiation Workshop, Atlanta, GA, May 8-9, 1986.

38. Ott, W.R., "XUV Radiometric Standards at NBS," SPIE 30th Annual Technical Symposium, San Diego, CA, August 17-22, 1986.

39. Parr, A.C., "Future Directions for Atomic and Molecular Physics," Workshop on Advanced Soft X-Ray and Ultraviolet Synchrotron Source, University of California, Berkeley, CA, November 13-15, 1985.

40. Parr, A.C., "Photoionization Studies Using Synchrotron Radiation," Hebrew University, Jerusalem, Israel, February 3, 1986.

41. Penn, D.R., "A General Expression for the Coulomb Interaction in the Presence of a Surface," American Physical Society, Las Vegas, Nevada, March 31, 1986.

42. Pierce, D.T., "Spin Polarized Inverse Photoemission in Panel on Experimental Methods in Surface Magnetism," International Colloquium on Magnetic Films and Surfaces, Asilomar, CA, September 2, 1985.

43. Pierce, D.T., "Investigations of Surface Magnetism Using Spin Polarized Inverse Photoemission," Mexican National Conference on Surfaces and Interfaces, Monterrey, Mexico, October 18, 1985.

44. Pierce, D.T., "Spin Polarized Electron Studies of the Magnetic Properties of Thin Films and Surfaces," Control Data Corporation, Minneapolis, MN, October 28, 1985.

45. Pierce, D.T., "Spin Polarized Electron Studies of the Magnetic Properties of Thin Films and Surfaces," Universidade Feral Fluminense, Niteroi, Brazil, December 4, 1985.

46. Pierce, D.T., "Investigation of Surface Magnetism Using Spin Polarized Electrons," Centro Brasileiro de Pasquisas Fisicas, Rio de Janeiro, Brazil, December 6, 1985.

47. Pierce, D.T., "Magnetic Properties of Surfaces Investigated by Spin Polarized Electron Beams," International Workshop on the Magnetic Properties of Low Dimensional Systems, Taxco, Mexico, January 6, 1986.

48. Pierce, D.T., "Electron Spin Polarization Analyzers," National Science Foundation, Materials Research Group (NSF/MRG) Site Visit, Brookhaven National Laboratory, Upton, NY, March 24, 1986.

49. Pierce, D.T., "Spin Polarized Electron Phenomena," Naval Research Laboratory, Washington, DC, May 14, 1986.

50. Pierce, D.T., "Surface Magnetism-Experimental Studies Using Electrons," Defense Advanced Research Projects Agency (DARPA) Workshop on Magnetism and Magnetic Materials, La Jolla, CA, July 21, 1986.

51. Pierce, D.T., "Scanning Electron Microscopy with Polarization Analysis," Physics Seminar, University of California, La Jolla, CA, July 22, 1986.

52. Pierce, D.T., "Spin Polarized Auger Spectroscopy and SEMPA Studies of Magnetism at Surfaces, Stanford Electronics Laboratory Seminar, Stanford University, Stanford, CA, July 25, 1986.

53. Unguris, J., "Spin Polarized Electron Studies of Magnetic Materials," Kodak Research Laboratories, Rochester, NY, October 16, 1985.

54. Unguris, J., "Magnetic Imaging Using Scanning Electron Microscopy with Polarization Analysis," Magnetics Technology Center Seminar, Carnegie-Mellon University, Pittsburgh, PA, October 29, 1985.

55. Unguris, J., "Magnetic Microstructure Study Using Scanning Electron Microscopy with Polarization Analysis," American Physical Society, Las Vegas, NV, March 1986.

PUBLICATIONS

Division 533, Radiation Physics

Berry, H.G., and Hardis, J.E., Measurements of the $1s2s^3S_1$-$1s2p^3P_{0,2}$ Wavelengths in Heliumlike Neon, Phys. Rev. A 33, 2778 (1986).

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Bizau, J.M., Cubaynes, D., Gerard, P., Wuilleumier, F.J., Picqué, J.L., Ederer, D.L., Carré, B., and Wendin, G., Experimental and Theoretical Determinations of the 5d Photoionization Cross Section in Laser-Excited Barium Atoms Between 15 eV and 150 eV Photon Energy, Phys. Rev. Lett. 57, 306 (1986).

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Bonanno, R.E., Clark, C.W, and Lucatorto, T.B., Multiphoton Excitation of Autoionizing States of Mg:I: Lineshape Studies of the $3p^2\ {}^1S$ State, Phys. Rev. A 34, (1986).

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Seiler, A., Feigerle, C.S., Peña, J.L., Celotta, R.J., and Pierce, D.T., Chemisorption Induced Changes in Surface Magnetism and Electronic Structure: Oxygen on Ni(110), Phys. Rev. B 32, 7776 (1985).

Snyder, J.J, Lucatorto, T.B., Debenham, P.H., and Geltman, S., Ultrasensitive Laser Isotope Analysis in an Ion Storage Ring, J. Opt. Soc. B 2, 1497 (1985).

Sonntag, B.F., Cromer. C.L., Bridges, J.M., McIlrath, T.J., and Lucatorto, T.B., Laser-XUV Excited State Spectroscopy, Proc. of the Third Topical Meeting on Short Wavelength Coherent Radiation: Generation and Applications (Monterey, CA, March 1986).

Southworth, S.H, Parr, A.C., Hardis, J.E., and Dehmer, J.L., Channel Coupling and Shape Resonance Effects in the Photoelectron Angular Distributions of the $3\sigma_g^{-1}$ and $2\sigma_u^{-1}$ Channels of N_2, Phys. Rev. A 33, 1020 (1986).

Taylor, K.T., Clark, C.W., and Fon, W.C., Electron Scattering by Neon in Resonance Regions, J. Phys. B 18 (1985).

Unguris J., Hembree, G.G., Celotta, R.J., and Pierce, D.T., High Resolution Magnetic Microstructure Imaging Using Secondary Electron Spin Polarization Analysis in a Scanning Electron Microscope, J. of Microscopy, 139, RP1 (1985).

Unguris, J., Hembree, G.G., Celotta, R.J., and Pierce, D.T., Investigations of Magnetic Microstructures Using Scanning Electron Microscopy with Spin Polarization Analysis, J. Magn. Mag. Mat., 54-57, 1629 (1986).

Unguris, J., Pierce, D.T., and Celotta, R.J., Low Energy Diffuse Scattering Electron Spin Polarization Analyzer, Rev. Sci. Instrum. 57, 1314 (1986).

PUBLICATIONS IN PREPARATION

Division 533, Radiation Physics

Bonanno, R.E., Snyder, J.J., Lucatorto, T.B., Debenham, P.H., and Clark, C.W., Ultrasensitive Laser Isotope Analysis of Krypton in an Ion Storage Ring, Proc. of the Third International Conference on Resonance Ionization Spectroscopy, September 8-12, 1986 (to be published).

Callcott, T.A., Tsang, K.L., Zhang, C.H., Ederer, D.L., and Arakawa, E.T., A High Efficiency Soft X-ray Emission Spectrometer for use with Synchrotron Radiation Excitation, Rev. Sci. Inst. (to be published).

Canfield, L.R., New Far Ultraviolet Detector Calibration Facility at NBS, Appl. Optics (in preparation).

Canfield, L.R., and Swanson, N., Far Ultraviolet Detector Documentation, NBS SP 250-2 (in preparation).

Celotta, R.J., and Pierce, D.T., Polarized Electron Probes of Magnetic Surfaces, Science (to be published).

Dragoset, R.A., Young, R.D., Layer, H.P., Mielczarek, S.R., Teague, E.C., and Celotta, R.J., Scanning Tunneling Microscopy Applied to Optical Surfaces, Applied Optics (in press).

Hembree, G.G., Unguris, J., Celotta, R.J., and Pierce, D.T., Magnetic Microstructure Imaging by Secondary Electron Spin Polarization Analysis, Proc. of the 44th Meeting of the Electron Microscopy Society of America (to be published).

Hill, W.H., Sugar, J., Cheng, K.T., and Lucatorto, T.B., Absorption Spectrum of Ba^{++}: $5p^6 \rightarrow 5p^5 ns,nd$, to be submitted to J. Opt. Sci. B (in preparation).

Hubbell, J.H., Gerstenberg, H.M. and Saloman, E.B., Bibliography of Photon Total Cross Section (Attenuation Coefficient) Measurements 10 eV to 13.5 GeV, NBS IR (to be published).

Jimenez-Mier, J., Caldwell, C.D., and Ederer, D.L., Oscillator Strength Distribution of Fluorescence from Photoionization Produced He+(n=2), Phys. Rev. Lett. (in preparation).

Johnson, B.C., Smith, P.L., and Parkinson, W.H, Transition Probability of the Al II 2669 Angstroms Intersystem Line, Astrophysical Journal, September 15, 1986 (in press).

Kelleher, D.E., and Saloman, E.B., Stark Effect of Rydberg States with Anistropic Ion Cores, Phys. Rev. (in preparation).

Keller, J.W., Ederer, D.L., and Hill, W. III, Polarized Fluorescence from the A and B States on O2+, Phys. Rev. A (in preparation).

Kostkowski, H.J., Lean J.L., Saunders, R.D., and Hughey, L.R., Comparison of the NBS SURF and Tungsten Ultraviolet Irradiance Standards, submitted to Applied Optics, May 1986.

Klebanoff, L.K., Photoelectron Spectroscopy Studies of Cr(001) Surface Ferromagnetism, Proc. International Workshop on Magnetic Properties of Low Dimensional Systems, Taxco, Mexico, January 6-9, 1986 (to be published).

Klebanoff, L.E., Baca, A.G., Schulz, M.A., Paparazzo, E., and Shirley, D.A., Dissociative Adsorption of CO and O_2 on Cr(100), and Cr(111) in the Temperature Range 300-1175K, Surf. Sci. (to be published).

Klebanoff, L.E., Tobin, J.G., Robey, S.W., and Shirley, D.A., The Development of a Three-Dimensional Valence Band Structure in Ag Overlayers on Cu(001), Phys. Rev. B (in preparation).

Klebanoff, L.E., Jones, R.K., Pierce, D.T. and Celotta, R.J., Spin-Polarized Inverse Photoemission Study of Ni(001) and Its Chemisorption, Phys. Rev. B (in preparation).

Lucatorto, T.B., Hutchinson, J.M.R, and Whitaker, T.J., Exploiting the Optical Isotope Shift for Ultrasensitive Isotopic Analysis with Lasers, Proc. of the 1986 Annual Meeting of the American Nuclear Society (Reno, NV, June 1986) (to be published).

McClelland, J.J., Kelley, M.H., and Celotta, R.J., State Selection in Electron-Atom Scattering: Spin-Polarized Electron Scattering from Optically Pumped Sodium, Proc. XIII Symposium on Physics of Ionized Gases, Sibenik, Yugoslavia (to be published).

Parr, A.C., Southworth, S.H., and Dehmer, J.L., Shape Resonance Effects in Photoionization of NO, Phys. Rev. (in preparation).

Parr, A.C., Dehmer, J.L., Hardis, J.E., and Southworth, S.H., Asymmetry Parameters for Vibrationally Resolved H_2, Phys. Rev. (in preparation).

Parr, A.C., Dehmer, J.L., Poliakoff, E., and Leroi, G., Polarization of Fluorescence and Carbon Disulfide, J. Chem. Phys. (in preparation).

Penn, D.R., Free Electron Like Stoner Excitations in Fe, J. of Appl. Phys. (to be published).

Penn, D.R., and Apell, P., A General Expression for the Coulomb Interaction in the Presence of a Surface (submitted to Phys. Rev.).

Penn, D.R., Electron Mean Free Path Calculations Using a Model Dielectric Function (submitted to Phys. Rev. Lett.).

Penn, D.R., Evidence for Free-Electron Like Stoner Excitation (submitted to Phys. Rev. Lett.).

Penn, D.R., and Apell, P., Theory of the Effective Coulomb Interaction in the Presence of a Surface, Solid State Communications (in preparation).

Pierce, D.T., Magnetic Properties of Surfaces Investigated by Spin Polarized Electron Beams, Proc. of International Workshop on the Magnetic Properties of Low Dimensional Systems, Taxco, Mexico, Springer-Verlag (to be published).

Pierce, D.T., Polarized Electrons at Surfaces, J. Opt. Soc. book review (to be published).

Saloman, E.B., and Hubbell, J.H., Critical Analysis of Soft X-ray Cross Section Data, submitted to Nucl. Instr. and Meth.

Saloman, E.B., and Hubbell, J.H., X-ray Attenuation Coefficients (Total Cross Sections): Comparison of the Experimental Data Base with the Recommended Values of Henke and the Theoretical Values of Scofield for Energies between 0.1-100 KeV, NBS IR 86-3431 (in press).

Southworth, S.H., Parr, A.C., Hardis, J.E., Dehmer, J.L., and Holland, D.M.P., Calibration of a Monochromator/Spectrometer System for the Measurement of Photoelectron Angular Distributions and Branching Ratios, submitted to Nucl. Instr. and Meth.

Tsang, K.L., Zhang, C.H., Callcott, T.A., Ederer, D.L., and Arakawa, E.T., Fluorescence Emission From Lithium Fluoride by Synchrotron Radiation Excitation, Phys. Rev. B (in preparation).

Wuilleumier, F.J., Ederer, D.L., and Picqué, J.L., Photoionization and Collisional Ionization of Laser Excited Atoms Using Synchrotron Radiation, chapter in "Advances in Atomic and Molecular Physics," Volume 23 (to be published).

TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION

Division 533, Radiation Physics

Robert J. Celotta

Member, General Committee, International Conference on the Physics of Electron and Atomic Collisions.

Member, NBS Computer Network Committee.

Member, NBS PC Committee.

Member, NML EEO Committee.

Charles W. Clark

Member, Technical Program Committee, Optical Society of America 1986 Annual Meeting.

Member, Organizing Committee, IV International Conference on Multiphoton Processes.

Member, Organizing Committee, Atomic Spectra and Collisions in External Fields II (Satellite Meeting of the XV International Conference on the Physics of Electronic and Atomic Collisions).

Chairman, Local Organizing Committee, 1988 Annual Meeting of the Division of Atomic, Molecular, and Optical Physics of the American Physical Society.

David L.Ederer

Member, Education Committee of the Optical Society of America.

Michael H. Kelley

NBS Advisory Group for Graphics.

NBS Atomic Physics Colloquium Committee.

Local Organizing Committee for 1988 Annual Meeting of the American Physical Society, Division of Atomic, Molecular, and Optical Physics.

Division 533, Technical and Professional Committee Participation and Leadership (cont'd)

Thomas B. Lucatorto

Advisory Panel, 1986 Conference on Laser Techniques in the Extreme Ultraviolet.

Co-chairman, 1989 International Conference on the Physics of Electron and Atomic Collisions.

Member, Program Committee, Resonance Ionization Spectroscopy Conference Series.

Robert P. Madden

Chairman, International Committee for the International Conference on VUV Radiation Physics.

Member, Synchrotron Radiation Center Users' Advisory Committee for the Stoughton Storage Rings (Tantalus and Aladdin) of the University of Wisconsin.

Member, Advisory Editorial Board on Optics Communication.

Member, Middle Atmospheric Program International Working Group on Solar Spectral Irradiance Measurements.

Member, Council of U.S. Synchrotron Radiation Laboratory Directors.

Member, International Committee of the International Conference on X-Ray and VUV Synchrotron Radiation Instruments.

Member, Advisory Committee for the Laboratory of Laser Energetics, University of Rochester, Rochester, NY.

Member, Optical Society of America Objectives and Policy Committee.

Member, Synchrotron Radiation Facility Working Group (Department of Energy).

Member, Interagency Group for Intense Light Sources.

Member, Synchrotron Radiation Source and Research Development Committee.

Division 533, Technical and Professional Committee Participation and Leadership (cont'd)

William R. Ott

Member, International Working Group for Middle Atmosphere Program on Solar Spectral Irradiance Measurements, 1981-1986.

Chairman, NBS-CRR Calibrations Advisory Committee.

Chairman, NBS-NML Performance Review Panel.

Daniel T. Pierce

Executive Committee, Surface Science Division of the American Vacuum Society.

Chairman, American Vacuum Society, Surface Science Division, 1986 Nominating Committee.

Local Arrangements Committee, 6th International Conference on Solid Surfaces, Baltimore,, MD, October 1986.

International Organizing Committee of the International Colloquium on Magnetic Films and Surfaces.

International Advisory Committee, 9th European Conferences on Surface Science, Lucerne, Switzerland, 1987.

National Science Foundation Materials Research Group for Spin Polarized Photoemission.

MAJOR CONSULTING AND ADVISORY SERVICES

Division 533, Radiation Physics

1. R.J. Celotta and D.T. Pierce consulted on the production and detection of polarized electrons with researchers from Brookhaven, AT&T Bell Labs, Bell Communications Corporation, University of Texas, Princeton, Kimball Physics Corporation, Rice University, University of Oklahoma, City College of New York, MIT, Argonne National Laboratory, Jet Propulsion Laboratory, Perkin Elmer Corporation, and the Naval Research Laboratory.

2. C.W. Clark advised a group at Princeton Plasma Physics Laboratory on atomic physics problems associated with x-ray laser development.

3. D.L. Ederer consulted with R. Freeman from AT&T Bell Laboratories on establishing a collaboration on laser-synchrotron, pulse-probe experiments and time-resolved spectroscopy at SURF-II.

4. T.B. Lucatorto consulted with R. Falcone of the University of California (Berkeley) on estalishing a collaboration to establish an ultrashort XUV measurement capability at NBS.

5. T.B. Lucatorto advised R. Falcone of the University of California (Berkeley) on spectroscopic measurements needed to understand x-ray laser emission from laser-produced plasmas, and proposed a collaboration to provide such measurements.

6. W.R. Ott consulted with P. Smith of Harvard College Observatory, M. Kühne of PTB, D. Nettleton of NPL, and M. Van Hoosier of NRL on recent developments in VUV radiometry and new possibilities for radiation standards.

7. A.C. Parr consulted with S. Southworth of Los Alamos, J. Dehmer of Argonne National Laboratories, and J. West of the Daresbury Synchrotron Radiation Laboratory on establishing a joint program on photo- ionization of molecules using synchrotron radiation.

8. D.T. Pierce consulted with R. O'Handley, MIT, on electron spin polarization analyzers and interfacing to experiments.

9. D.T. Pierce consulted with G. J. Lapeyre and C. Quing, Montana State University, on construction of a GaAs spin polarized electron source.

Division 533, Major Consulting and Advisory Services (cont'd)

10. D.T. Pierce consulted with W. Dinan and R. York, Continuous Electron Beam Accelerator Facility, (CEBAF), Newport News, VA, on using a GaAs cathode for the accelerator.

11. D.T. Pierce participated in Office of Naval Research meeting, Purdue University, entitled "Research Opportunities in Magnetism for Naval Applications."

JOURNAL EDITORSHIPS

Division 533, Radiation Physics

R.J. Celotta, Series Editor, Methods of Experimental Physics.

D.T. Pierce, Editorial Board, Review of Scientific Instruments.

D.T. Pierce, Editorial Board, Journal of Electron Spectroscopy and Related Phenomena.

TRIPS SPONSORED BY OTHERS

Division 533, Radiation Physics Division

R. E. Bonanno presented a talk at Atom Sciences, Inc., Oak Ridge, TN, February 26, 1986.

R. E. Bonanno presented a talk at Lawrence Livermore National Laboratory, Livermore, CA, April 9, 1986.

R. E. Bonanno visited William Paterson College and presented a talk, Wayne, NJ, April 22, 1985.

R. E. Bonanno attended the Resonance Ionization Spectroscopy (RIS) Conference and presented an invited talk, Swansea, Wales, September 9, 1986.

R. E. Bonanno collaborated with Jeff Paisner at Lawrence Livermore National Laboratory, Livermore, CA, August 19-22, 1986.

R. J. Celotta presented a talk at the 1986 Pittsburgh Conference on Analytical Chemistry and Applied Spectroscopy, Atlantic City, NJ, March 10, 1986.

R. J. Celotta presented a colloquium to the Joint Institute for Laboratory Astrophysics, Boulder, CO, April 21, 1986.

R. J. Celotta presented a talk to the New England Society for Electron Microscopy, Woods Hole, MA, May 10, 1986.

R. J. Celotta presented a talk to the Vacuum '86-Processing Technology Conference, Nashua, NH, June 9, 1986.

R. J. Celotta presented an invited talk to the Joint Meeting of the American Vacuum Society and IEEE Magnetics Society, Rochester, NY, June 12, 1986.

C. W. Clark consulted on X-Ray Laser Development at Princeton Plasma Physics Laboratory, Princeton, NJ, November 14, 1985.

C. W. Clark gave a seminar at the University of Delaware, Newark, DE, December 1, 1985.

C. W. Clark consulted on X-Ray Laser Development at Princeton Plasma Physics Laboratory, Princeton, NJ, December 19, 1985.

C. W. Clark worked on a review article in collaboration with Dr. Stephen Buckman, Australian National University, Canberra, Australia, January 19-23, 1986.

C. W. Clark attended the Fourth Australian Conference on Atomic and Molecular Physics and Quantum Chemistry and gave a lecture, Tasmania, Australia, January 24-27, 1986.

C. W. Clark attended the Fourth International Symposium on Quantum Optics and presented a paper, Hamilton, New Zealand, February 9-14, 1986.

C. W. Clark consulted on X-Ray Laser Development at Princeton Plasma Physics Laboratory, Princeton, NJ, March 13, 1986.

C. W. Clark attended a workshop organizing committee meeting, and presented a paper, European Center for the Calculation of Atomic and Molecular Properties, Orsay, France, April 29, 1986.

C. W. Clark consulted on X-Ray Laser Development at Princeton Plasma Physics Laboratory, Princeton, NJ, May 27, 1986.

C. W. Clark gave an invited lecture at the NATO Advanced Study Institute on Giant Resonances in Atoms, Molecules, and Solids, Les Houches, France, June 18, 1986.

D. L. Ederer gave a talk at the University of Central Florida, Orlando, FL, April 23, 1986.

B. C. Johnson visited the Center for Astrophysics and consulted with W.H. Parkinson, P.L. Smith, and D.W. Dugnette on a collaborative experiment, Cambridge, MA, February 26-March 6, 1986.

B. C. Johnson visited the Department of Physics at the University of Nevada, Reno, NV, June 23-25, 1986.

T. B. Lucatorto attended the program committee meeting on Short Wavelength Coherent Radiation and visited Roger Falcone, Lawrence Berkeley Laboratory, Berkeley, CA, January 9-10, 1986.

T. B. Lucatorto presented a colloquium at University of Virginia, Charlottesville, VA, March 25-27, 1986.

T. B. Lucatorto presented a seminar at the University of Toronto, Toronto, Canada, April 8, 1986.

R. P. Madden attended an Advisory Committee Meeting, University of Rochester, Rochester, NY, February 27-28, 1986.

A. C. Parr visited Daresbury Laboratory to consult with John West, Warrington, England, February 15-23, 1986.

D. T. Pierce presented a talk at Control Data Corporation, Minneapolis, MN, October 28, 1985.

D. T. Pierce presented a talk to the Physical Electronics Division, Perkin Elmer Corp., Minneapolis, MN, October 29, 1985.

D. T. Pierce presented a talk to the International Workshop on the Magnetic Properties of Low Dimensional Systems, Taxco, Mexico, January 6-9, 1986.

D. T. Pierce presented a talk to the Defense Advanced Research Project Agency (DARPA) Workshop on Magnetism and Magnetic Materials, La Jolla, CA, July 21, 1986.

CALIBRATION SERVICES PERFORMED

Division 533, Radiation Physics

Type of Service	Customer Type*	SP 250 Item No.	Number of Calibrations or Tests
Far UV radiometric transfer standard detectors (photo-diode calibrations)	1,4-8	N.A.	21
Spectrometer cali-brations using SURF as an absolute source	5-7	N.A.	28
Totals			49

*Column 2: 1, calibration labs; 2, hospitals; 3, nuclear energy establishments; 4, industry; 5, US government labs; 6, DoD labs; 7, universities; 8, foreign governments.

SPONSORED SEMINARS AND COLLOQUIA

Division 533, Radiation Physics

Cohen, M.L., Physics Department, University of California at Berkeley, "Predicting New Solids and Superconductors," April 25, 1986.

Cooke, W., University of Southern California, Los Angeles, CA, "Branching Ratios of Short-Lived States," February 18, 1986.

Chubb, S., Naval Research Laboratory, Washington, DC, "Structural and Electronic and Magnetic Structure Study of Chemisorption Bonding: C(2X2)O/Ni(001)," December 18, 1985.

Erickson, W.C., University of Maryland, College Park, MD, "Observation of High Rydberg States in the Interstellar Medium," November 8, 1985.

Fain, S.C., University of Washington, Seattle, WA, "Structures and Phase Transitions of Oxygen on Graphite," March 14, 1986.

Ferret, T., Lawrence Berkeley Laboratory, Berkeley, CA, "Resonant Effects in Core Level Photoionization of Molecules," March 12, 1986.

Guntherodt, G., University of Cologne, Cologne, West Germany, "Spin-Resolved Photoemission of Epitaxial Layers (Fe/W(110)) and Adsorbates (Ni(110): o,s)," June 27, 1986.

Harmin, D.A., University of Colorado, Boulder, CO, "Field Enhancement of Dielectronic Recombination," October 18, 1985.

Hayman, C., Lawrence Livermore Laboratory, Livermore, CA, "Laser Isotope Separation Spectroscopy as Applied to Gd," October 1, 1985.

Hertel, I.V., Department of Physics, Institute for Molecular Physics, Free University of Berlin, West Berlin, West Germany, "Alignment and Orientation in Collisions of Laser Excited Atoms with Electrons, Ions, Atoms, and Molecules," February 18, 1986.

Hubert, A., University of Erlangen, Erlangen, West Germany, "Domain Observation with a Digitally Enhanced Kerr Microscope," June 26, 1986.

Kelly, H., University of Virginia, Charlottesville, VA, "Recent Many Body Photoionization Calculations," January 13, 1986.

Kühne, M., Physikalisch Technische Bundesanstalt, West Germany, "VUV Radiometry at the PTB Laboratory," September 2, 1986.

Leventhal, J., University of Missouri, St. Louis, MO, "Ionization of Rydberg Atoms," February 13, 1985.

Mills, D., Cornell University, Ithaca, NY, "Laser Pump and X-ray Probe Experiments at CESR," January 6, 1986.

Morgan, J.D., University of Delaware, Newark, DE, "The 1/Z Expansion for Atoms, November 1, 1985.

Nicolaides, C.A., National Hellenic Research Foundation, Athens, Greece, "Theory of Doubly-Excited States and the Wannier Ionization Law," October 17, 1985.

Paisner, J., Lawrence Livermore Laboratory, Livermore, CA, "Review of AVLIS/Work on Process Development for Laser Isotope Separation," January 6, 1986.

Pouey, M., CNRS-University Paris Sud, France, "Stigmatic XUV Plane and Spherical Grating Spectrometers," October 18, 1985.

Prybyla, J., Department of Chemistry, Brown University, Providence, RI, "Phase Diagrams, Surface Structure and Desorption Kinetics for the Hydrogen on Molybdenum (100) Chemisorption System," April 15, 1986.

Schnatterly, S., University of Virginia, Charlottesville, VA, "Band Structure Studies by Soft X-ray Emission Spectroscopy," January 15, 1986.

Seigmann, H.C., ETH-Zurich, Switzerland, "Magnetic Measurements with Electrons," March 13, 1986.

Sharma, J., Naval Surface Weapons Laboratory, Silver Spring, MD, "XPS Study of Explosives," November 15, 1985.

Sheorey, V.B., Physical Research Laboratory, Ahmedabad, India, "Fluctuation Properties of Regular and Irregular Spectra and Quantum Chaos," January 14, 1986.

Tersoff, J., IBM, "Theory of the Scanning Tunneling Microscope," November 27, 1985.

van der Brugt, P.J.M., North Carolina University, Raleigh, NC, "Shape Resonances and the Excitation of Helium Autoionizing States by Electrons," May 20, 1986.

Wells, O., IBM Watson Research Center, Yorktown Heights, New York, "Studies of Magnetic Samples in the SEM," February 12, 1986.

Whitaker, T., Batelle Northwest Laboratories, Richland, WA, "High-Resolution Resonant Ionization Spectroscopy," November 14, 1985.

Wuilleumier, F., University Paris Sud, France, "Present Status and Future Developments of the Laser-Synchrotron Radiation Ionization Studies," November 7, 1985.

TECHNICAL ACTIVITIES

Division 534, Radiometric Physics

Introduction

The Radiometric Physics Division of the Center for Radiation Research is the primary unit within NBS for carrying out the traditional Bureau role of promoting accurate, meaningful, and compatible optical radiation measurements in the near-uv, visible, and near-ir spectral regions. Measurement services, as well as research and development, in these areas are essential to the U.S. defense, aerospace, health, lighting, photographic, and other industries for product development, quality control, and to assure a competative position in world markets. Government agencies, such as DoD and NASA, also reply on the NBS measurement base for high-technology applications involving radiometry and spectrophotometry in the above-mentioned regions.

The Division was organizationally subdivided into four Groups during FY 1986:

Spectroradiometry and Optical Pyrometry. Conducts applied research to develop new instrumentation and to improve and extend radiometric and pyrometric standards and calibration procedures.

Spectrophotometry. Provides high-accuracy spectrophotometric measurements, standards, and measurement assurance procedures. Develops new methods for the radiometric characterization of optical media and components.

Photodetector Physics and Metrology. Develops new, detector-based radiometric standards and methods to complement and extend traditional, source-based radiometry.

Radiometric Measurement Services. Provides, improves, and extends radiometric and photometric calibrations, implements measurement assurance programs, and participates in radiometric intercomparisons.

As will be seen from the following reports of the four Group Leaders, each Group produced important results during the fiscal year.

Fiscal year 1986 was a year of transition for Division 534. Three employees, Alfred Crigler, John Shumaker, and John Ward, have retired during the year. Russell Yokley has also retired, but agreed to continue working on infrared radiometry on a contract basis. We have filled one of the vacancies left by these retirements by hiring Mr. Gasem Jaafari, a physicist with previous experience in blackbody physics and radiation thermometry. Two junior physicists at the postdoctoral level, Dr. Jonathan Hardis and Dr. Alan Midgall, will join the Division at the beginning of FY 1987. As a further measure, several changes in personnel assignments and group responsibilities were made.

The Spectroradimetry and Optical Pyrometry Group has begun to implement the new spectroradiometry effort of the NBS Process and Quality Control Initiative. James J. Snyder, formerly with the NBS Center for Basic Standards, joined the Division for several months, and was given the assignment to identify new research directions for the Group. He formulated plans for five projects,

Laser Heterodyne Densitometry,
XUV Absolute Radiometry,
IR Heterodyne Pyrometry,
Fourier Spectroradiometry,
Rydberg Atom IR Detection,

which are expected to bring new impetus to radiometry through the exploration of new technologies. James Snyder also undertook a survey of national needs for low-background infrared calibrations and negotiated contracts to develop a cryogenic radiometer for such calibrations at NBS. Although Snyder has left the Division to accept a position in private industry, new activities in these areas have started with newly hired scientists and with technical advice from Tom Lucatorto of Division 533.

The Spectrophotometry Group has again increased the number and volume of Standard Reference Materials produced. Victor Weidner developed a new technique in sintering halon mixtures and has applied it to produce new SRM's for reflectance and fluorescence measurements. The Group also conducted transmittance intercomparisons with the National Physical Laboratory of the U.K., and the Physikalisch-Techische Bundesanstalt of the FRG, both of which have now developed reference spectrophotometers patterned after the NBS high-accuracy spectrophotometer designed by Klaus Mielenz and Kenneth Eckerle.

The responsibilities of the Photodetector Physics and Metrology Group have been broadened to include the development and implementation of metrological applications of detectors in addition to performing basic research. The Group has already made significant progress in detector metrology, especially in the international intercomparison of silicon detectors conducted by Edward Zalewski under the auspices of the Consultative Committee on Photometry and Radiometry (CCPR) and in the low-light level radiometry project headed by Schaefer. FY 1986 was the last year of the Division's Quantum Radiometry project, and consequently our previous efforts in developing non-radiometric measurement technqiues, characterization methods, and theoretical descriptions of semiconductor photodiodes have been transferred to the Semiconductor Electronics

Division (727) of the NBS Center for Electronics and Electrical Engineering. Jon Geist has transferred to Division 727, and both Divisions (534 and 727) have agreed to collaborate in research on semiconductor devices suitable for radiometric measurements. The responsibility for the development and radiometric calibration of solid state detectors will remain in Division 534. Schaefer has been appointed Acting Group Leader, and the Group will be merged with the Spectroradiometry and Optical Pyrometry Group in FY 1987.

The Radiometric Measurment Services Group has achieved excellent agreement with measurements made by other leading national standardizing laboratories in an international intercomparison of luminous intensity and luminous flux, also conducted by the CCPR. In collaboration with the Photodetector Physics and Metrology Group, it has demonstrated better than 0.5% agreement between detector- and source-based photometric scales in a filter radiometry experiment conducted by Robert Bruening and in joint efforts with Hungarian radiometrists. Donald McSparron has led the Division's participation in the NBS-wide effort to prepare comprehensive documentation of calibration and measurement services.

The Division as a whole continued to be actively engaged in collaborative efforts with other standardizing laboratories, professional societies, and standards organizations at the national and international levels. For example:

- Our exchange program with the Physikalisch-Technische Bundesanstalt (PTB) is now in its third year. Robert Saunders and James Walker both worked in Braunschweig during FY 86, and Dr. Metzdorf from PTB will join us as a guest scientist later this year.

- Jack Hsia was elected as a Director of the Inter-Society Color Council. Mielenz was elected Director of Division 2, "Physical Measurement of Light and Radiation," of the International Commission on Illumination (CIE).

- Mielenz organized an international conference on "Advances in Standards and Methodology in Spectrophotometry" in collaboration with the US Council for Optical Radiation Measurements (CORM) and the UV Spectrometry Group of the UK. Several Division employees presented invited lectures at this conference.

The number of guest scientists who work in our laboratories on projects of mutual interest has again been substantial:

Dr. Joaquin Campos Acosta from the Institute of Optics in Madrid, Spain, made linearity measurements in the infrared of pyroelectric and HgCdTe detectors on the new CO_2 laser-based detector characterization facility.

Mr. Gyorgy Andor from the Hungarian Office of Measures worked on filter detector spectral radiometry and the realization of a detector-based photometric scale.

Messrs. Sheng-Tsong Chang and Chang-Long Chang from the National Science Council of Taiwan participated in the development of spectrophotometric standards.

Dr. Gyula Deszi from the Hungarian Office of Measures (OMH) performed a detector intercomparison to check NBS and OMH detector scale agreement, and to compare photopic detectors with the NBS photometric scale.

Dr. Gyorgy Eppledauer from the Institute for Technical Physics of the Hungarian Academy of Science worked on international detector intercomparisons, and the low light level detector radiometry program.

Professor He Ming-Gao from the Institute for Electric Light Sources of Fudan University, Shanghai, PRC, collaborated on the intermediate laboratory support program for geometrically-total spectral flux.

Mr. Kemal Kumcu from TUGAM - Marmara Research Institute, Turkey, worked on the CW ring dye-laser facility and aided in characterization measurements of a high quality NPL interference filter with this facility.

Mr. Fred Nicodemus, Catholic University of America, Washington, DC, edited the Self-Study Manual on Optical Radiation Measurements.

Mr. Yoshihiro Ohno of the Matsushita Electric Industrial Company in Osaka, Japan, worked on characterizing the throughput of small integrating spheres for measurments of geometrically total luminous flux.

Dr. Janos Schanda from the Hungarian National Academy of Sciences (MFKI) participated in photometric detector intercomparisons with our division.

Dr. Masura Tsudagawa from Ritsumeikan University in Japan aided in the characterization and extension of detector scales into the near infrared region, using an electrically calibrated radiometer. He studied the use of such detectors as Ge and InP/InGaAs.

Mr. Zhang Rui-Rong of the Shanghai Institute of Technical Physics, Peoples' Republic of China made measurements of detector reflectance, cleaning procedures, and the effect on stability.

Their contributions to our programs are acknowledged with thanks.

Spectroradiometry and Optical Pyrometry (J. J. Snyder, A. R. Schaefer)

Infrared Radiometry

Yokley has almost finished the characterization of the new heat-pipe blackbody constructed at the beginning of last year to meet the needs of the infrared radiation thermometry community. Both sodium-filled (500°C to 1100°C) and mercury-filled (200°C to 350°C) units have been prepared.

Snyder conducted a survey of the needs of the defense community in the area of low background long wavelength infrared (LWIR) calibration capability. The LWIR capability which Yokley had established a number of years ago is no longer available. It was determined that a reinstatement of this capability in-house would require an inordinate effort. To meet the future growing needs of the LWIR community, the Army USADC/SDI Command has funded the development of a low background LWIR calibration facility in our Division at NBS. Progress to date includes conceptual design of the cryogenic chamber and closed cycle helium refrigeration system to provide necessary cooling capacity. Work is also progressing on design of an electrically calibrated cryogenic radiometer necessary for use in the facility. Yokley has also been active in these areas. In addition, Joel Fowler and Schaefer have recently become involved in this effort.

Spectroradiometry

Saunders and Shumaker have made further progress in the absolute gold point determination experiment. Saunders characterized an electrically calibrated absolute radiometer and compared it to the PTB radiometer scale while a guest worker there. The results were quite encouraging, with absolute agreement within 0.3%. Since that time the entire measurement sequence necessary to determine the gold point has been performed, after assembling all the necessary apparatus. In connection with this project, Saunders and Shumaker have developed a computer controlled gold-point blackbody possessing stable freezing and melting times of an hour. This is a factor of four better than previous efforts at NBS. This experiment is now in its final stages. The conclusion of this effort may be somewhat delayed due to the recent retirement of Shumaker.

Migdall worked with Snyder in moving and setting up the helium/neon laser version of the heterodyne densitometer prior to Snyder's departure. It is expected that work will proceed on this project beginning in October. In addition, Zalewski is interested in pursuing LWIR laser heterodyning on the CO_2 laser facility.

Saunders and Ohno developed techniques and built an ion and dye-laser based apparatus for measuring the absolute spectral power throughput of integrating spheres. The device was also used to measure the relative spectral response of several detector-filter combinations. The results of this work were used to confirm data taken on the spectral response comparator described later in this report.

Geist, Saunders, and Jeanne Houston investigated the effects of detector biasing in the UV. This work was made possible by the use of the newly developed spectral response comparator. Results from these measurements have helped lead to the development of better detectors in the UV spectral region.

In collaboration with the Radiation Physics Division Regina Bonanno has been doing postdoctoral research with Snyder, constructing the ion charge exchange facility. This apparatus is in the final stages of becoming operational, and Bonanno hopes to complete the intended feasibility studies before leaving NBS in early October. Her intent is to investigate the single-pass laser ionization efficiency and effectiveness of charge exchange in populating a desired metastable state in Kr necessary for certain isotopic analysis schemes to work. The longer term goal for this facility is to generate a known amount of XUV radiation for a measured number of visible photons produced. It is also anticipated that Hardis will spend a substantial effort on this project.

Spectrophotometry (J. J. Hsia)

The Spectrophotometry group is responsible for:

(1) Establishing and improving high-accuracy spectrophotometric, spectrofluorimetric and densitometric scales in the National Mesurement System by developing new instrumentation, establishing new measurement capabilities, and improving basic standards.

(2) Disseminating these scales by developing transfer standards and standard materials, establishing measurement assurance programs, performing calibration services, and providing consultation to the measurement community.

(3) Studying and developing new methods for radiometric characterization of optical media and components for scientific research and for emerging technologies.

FY 1986 has been a productive year for the Group in terms of research, development and measurement services. Major accomplishments in the areas of UV-VIS-NIR spectrometry, infrared spectrometry, spectrofluorimetry, transmission densitometry, and standard committees are presented below.

UV-VIS-NIR Spectrometry

Measurement Services

Calibrations, standards, and testing methods in the wavelength range from 200 nm to 2.5 μm are needed to serve many industries including: optics, non-destructive testing, energy, safety, space, agriculture, appearance, photography, printing, textiles, paint, and chemicals.

Weidner and Patricia Barnes provided special calibrations of spectral transmittance, specular reflectance, and diffuse reflectance. Eckerle provided measurement assurance services for transmittance and Hsia provided calibrations of gloss samples.

Two documents have been completed describing the instrumentation, standards, and techniques used in the measurement of spectral reflectance (Weidner and Hsia) and spectral transmittance (Eckerle, Hsia, Mielenz, and Weidner). Detailed descriptions are provided of the reference and transfer instruments, instrument calibration, establishment of scales, measurement procedures, and estimation of uncertainties. These two documents will be published as NBS special publications.

Transmittance

The seven glass filters in the set of transmittance standards developed by Eckerle for the NBS measurement assurance program, have proved to be very useful. Weidner used these filters at 548.5 nm and 770 nm to establish the linearity of the transfer spectrophotometer for the visible and near infrared spectral regions. Eckerle used them to perform an intercomparison with the Munsell Laboratory at the Rochester Institute of Technology as a step toward the establishment of a secondary calibration laboratory. Eckerle also started intercomparisons using this set of filters with George Freemen of the National Physical Laboratory, Great Britain and with E. Sutter of the Physikalisch-Technische Bundesanstalt, Federal Republic of Germany. Both laboratories have recently completed the development of high accuracy spectrophotometers for transmittance.

Andor investigated the spectral transmittance of $V(\lambda)$ filters using the NBS high accuracy spectrophotometer for transmittance.

Reflectance

Pressed polytetrafluoroethylene (PTFE) powder has been widely used for reflectance standards since Weidner and Hsia published their paper in July 1981 in the Journal of Optical Society of America. The PTFE powder has very high spectral reflectances from 200 nm to 2500 nm. Laboratories in NASA and USDA have consulted Weidner on producing large size PTFE plates for use as reflectance standards in their particular applications.

One of the frequent requests from instrument manufacturers and users has been a set of gray reflectance standards with diffuse surfaces to check the linearity of spectral reflectometers. Weidner has successfully produced uniform gray diffusers for reflectance below 50%, with sintered mixtures of PTFE and carbon-black powders. For a sintered mixture with reflectance above 50%, uniform reflectance was difficult to achieve because the required amount of carbon black powder to mix with the PTFE powder is small.

Weidner and Barnes completed the production of SRM 1920 rare-earth oxide mixtures as wavelength standards for spectral reflectometers in the near infrared range. These standards will soon be issued by the Office of Standard Reference Materials. SRMs 1920 are especially useful for those instruments that can only be used to measure the reflectance of samples. These instruments are generally used to evaluate constituents such as protein, moisture, etc. in grains.

Automation Conversion

The reference spectrophotometer for reflectance has been the basic instrument used by NBS to establish U.S. national scales of specular reflectance, 6°/hemispherical reflectance factor and 45/0° reflectance factor. Marvin Wu, a summer student from Brown University, started the conversion of the data acquisition and control units to use the IBM-GPIB system. The conversion involved such hardware as a microcomputer, digital voltmeter, lock-in amplifier, relay module, stepper motor drivers and software using the T BASIC language.

Infrared Spectrometry

Many requests for measurement services in the infrared spectral region have been received from instrument manufacturers, the optical industry, the glass industry, and DoD related industries. The purpose of the long-wavelength infrared spectrometry project is to establish the infrared measurement capabilities from 2.5 to 25 µm, especially from 3 to 5 µm and from 8 to 14 µm, for transmittance, diffuse reflectance and specular reflectance. The plan is to develop dual systems with both Fourier transform (FT) and dispersive infrared spectrometers.

Weidner has tested the signal throughput of the specular reflectometer with a liquid-nitrogen cooled HgCdTe detector and found it satisfactory. The spectral reflectance and transmittance of germanium filters of 2, 4, and 6 mm thickness were measured from 2 to 2.5 µm on the transfer spectrometer. The calculated internal transmittances were near 100% which confirmed that the germanium had no absorption in certain wavelengths in the infrared region. These filters will be used to check the specular reflectance and transmittance measurements of the FT-IR spectrometer and the transmittance measurements of the dispersive spectrometer.

For the diffuse reflectometer which uses an ellipsoidal mirror, a small averaging sphere with a gold-coated sand-blasted inner surface was designed and constructed. This averaging sphere, when used with the nitrogen-cooled HgCdTe detector, did not produce enough signal to allow meaningful measurements. A new design was produced with a hemispherical dome shaped shell over the detector. The infrared radiation was thus focused on the detector. The newly designed detector was checked. Because a leak developed between the dome and the detector, the detector was sent back to have it resealed.

The determination of large attenuations poses difficult problems for many users. The idea of using a sphere-chain attenuator (SCA) is to measure the attenuation of one or two spheres and to calculate the attenuation of a chain of many spheres. Hsia has collaborated with Ohno on the modeling of an SCA. The assumptions were a Lambertian wall coating and uniform luminance on the sphere wall. The modeling was performed for different sphere arrangements, sphere parameters, and coating reflectances. The modeling was also performed for different methods of calibrating the SCA. The results of the modeling provided information on optimum sphere arrangements and calibration methods.

Spectrofluorimetry

The purpose of this project is to develop measurement methods and transfer standards in order to assess the performance of instruments for fluorescence measurements applicable to analytical chemisty, non-destructive testing, and appearance measurements.

Weidner has successfully produced sintered mixtures of inorganic phosphors and PTFE powder. Four kinds of mixtures were sintered that yielded receiver-system corrected, normalized emission spectra in the blue, green, yellow, and orange wavelength regions of the visible spectrum. The spectral properties of PTFE made it ideal for this application because of its low absorption in the ultraviolet and visible spectral regions.

Eckerle and Chang investigated the fluorescence properties of these sintered fluorescence samples. They investigated the effects of the following parameters on the normalized emission spectra: excitation wavelength, ultraviolet exposure, temperature, and concentration of the phosphors. They also investigated the uniformity of these samples. The investigations were undertaken to search for possible reference materials for use as fluorescence standards.

Transmission Densitometry

Measurements of transmission density are used for quality control of photographic and printing products and for non-destructive testing.

Laurance Fink produced x-ray step tablets (SRM 1001) and photographic step tablets (SRM 1008) used in the calibration of transmission densitometers for transmission densities from 0 to 4 and microcopy resolution charts for determining the resolving power of photographic systems. Reflection step tablets (SRM 2061) which have been calibrated by Fink, are also available from the Office of Standard Reference materials for reflection densities from 0 to 2.

The reference transmission densitometer has been constructed with the unique feature that the transmission density of a sample is inversely proportional to the fourth power of the ratio of the sample-in distance to the sample-out distance. The receiver, built to conform to the new ANSI Standard PH2.19-1986, was found to produce non-uniform flux on the photomultiplier. A new receiver has been designed by Fink and built by the machine shop. This receiver consists of an opal glass, a sample plate with grooves for applying vacuum or pressure, a small section of specular-aluminum cone, and an averaging sphere. A photomultiplier with a high sensitivity GaAs (Cs) photocathode has been ordered. This photomultiplier has a relatively flat spectral response in the visible region. A compound filter with a spectral transmission resembling the CIE standard luminosity function will be used over the new detector.

Standards Committees

Hsia served both as an Associate Director and the Secretary of CIE Division 2 on Physical Measurement of Light and Radiation. He also served as a member of Committee TC2-14 on Transmittance and Reflectance. As the Chairman of Committee TC2-11 on gonioreflectometry, he has planned a world wide investigation of the gonioreflectance properties of standard reference materials, specially PTFE and $BaSO_4$ powders.

Hsia also served as a Director on the Board of the Inter-Society Color Council, an inter-disciplinary organization of more than 20 scientific, artistic and industrial societies which have common measurement problems in color and appearance.

At the CORM/UVSG Spectrophotometry Conference in Oxford, England, Hsia was invited to speak on "National Scales of Spectrometry in the U.S.", Mielenz on "Fluourescence Spectometry in Analytical Chemistry and Color Science", and Schaefer on "Tunable Dye Laser Spectrometry".

Julius Cohen's standard test method for minimum resolvable temperature differnce (MRTD) has been approved by subcommittee ASTM E7.10 on other NDT Methods. He has also completed a draft on "Fundamentals and Applications of Infrared Thermography for Nondestructive Testing".

Photodetector Physics and Metrology (J. C. Geist, A. R. Schaefer)

Photodetector Calibrations

Houston, Saunders, and Zalewski have made progress on the detector spectral response comparator. A new light proof box was designed and installed to enclose the detector compartment. Changes were made in the optics in the detector compartment to allow better focussing with improved precision resulting. Saunders is currently converting computer support for the facility from the old eight-bit system to the newer more flexible sixteen-bit PC computer system.

Andor and Zalewski designed a set of absorbing glass filters which will be used for absolute detector based, narrow-band filter spectroradiometry. It is expected that absorbing glass narrow-band filters will be more stable and uniform than the interference filter spectroradiometer such as that used previously by Bruening. The absolute base will be 100% quantum efficient detectors for longer wavelength measurements using promising new photodiodes now available. In addition, they are working to realize an absolute photometric scale based on 100% quantum efficient detectors with a carefully designed photopic glass filter.

Better quality detectors for use in radiometry are becoming available. Raj Korde of United Detector Technology, Inc. (UDT) has developed a device which has high quantum efficiency and is apparently very stable in the UV. These devices can be irradiated for several days with over 1 mW per square cm of 254 nm wavelength radiation with no apparent change in quantum efficiency. A special UV calibration of several of these new detectors has recently been completed by Houston and Zalewski for UDT and Optronics Laboratories. Both companies have experienced problems with UV detector calibration instability - changes as large as 20% in a few months. They have agreed to work with NBS over the next few years to monitor the UV calibration of these new detectors.

Recently Professor Schwartz of Purdue University has made progress in producing high quality germanium photodiodes for the near infrared spectral region. The devices have been measured at the University of Arizona Optical Sciences Center, and appear to have a very high internal quantum efficiency of essentially 100% from 0.7 to 1.5 μm.

Geist continued to cooperate with Petroff of Rockwell International on modeling of blocked impurity band silicon detectors.

Intercomparisons

Zalewski and Douglas Thomas, have obtained some very interesting initial results in the CCPR Detector Intercomparison. Seven national laboratories were sent a pair of photodiodes, one inversion layer and one PN device.

They were asked to determine the quantum efficiency of these two detectors at 632.8 nm. The detectors were first measured at NBS, and then measured again upon their return. The range of agreement for the majority of the laboratories (six out of eight including NBS) was within ±0.15% for the inversion layer type of photodiode. These excellent results were clouded somewhat by the fact that the quantum efficiency of some of the detectors had changed during transport. It appeared, however, that the change occurred between the first NBS measurement and that done at the other laboratory; i.e., on the outward leg of the trip. The PN layer devices seemed to show better stability than the inversion layer devices.

Water Bath Blackbody

The water bath blackbody described in last year's annual report has been finished and delivered to the Air Force CCG. This apparatus appears to successfully meet a need for ambient background LWIR calibrations. In view of its success, the Navy CCG has furnished support to construct another such device. Plans are underway to construct two such devices, in order to maintain an in-house capability. Also under consideration is an effort to construct an LWIR radiometer capable of characterization of such blackbody sources.

Low Light Level Detector Radiometry

This was a very successful year for the low light level program. Schaefer and Patraick Tobin finished the ultra-high precision low light level radiometer characterization facility which provides total light and vibration isolation and a high degree of thermal mechanical stability. The facility instrumentation is controlled with a personal computer. Schaefer used the new semiconductor parameter testing instrument to select good candidate detectors for use in the stellar radiometer at Lick Observatory for stellar brightness and planetary detection studies. This radiometer was designed in collaboration with A. Young of San Diego State University and W. Borucki of NASA Ames Research Center, and fabricated at NBS.

Fowler and Geist designed and constructed a very stable high gain amplifier, which produced a gain of 10^{11} V/A with a stability of better than 0.1%. Schaefer characterized and tested the final assembly of the radiometer, amplifier, and chosen detectors on the low light level facility, using tritium activated phosphorescent light sources. At current levels of 1 - 10 pA, relative amplified detector signal stabilities of $\sim 5 * 10^{-4}$ were obtained with 4 minute integration periods.

Schaefer, Fowler, and Tobin then took the radiometer and amplifier assembly to Lick Observatory at Mt. Hamilton, CA. With the assistance of William Borucki and Lori Allen, they installed the instrumentation on the Lick 19- inch twin astrograph telescope. Several nights worth of measurements yielded relative star brightness determinations on pairs of stars with a precision better than 1:10^3, which surpassed initial expectations. It is anticipated that with the adoption of cooled detectors and amplifiers, the precision will be increased further. The favorable results of this work resulted in a Letter of Commendation from David Brocker, Chief of the Space Sciences Division of the NASA Ames Research Center.

Spectral Radiometry

The high quality NPL/Anders interference filter loaned to NBS for evaluation by Neal Fox of NPL has been examined with the tunable ring dye-laser detector characterization facility. Schaefer and Kumcu used DCM dye to characterize the 20 nm half bandwidth 676 nm filter described in last year's annual report. Apparently these filters do indeed represent a new level of uniformity in transmittance, with peak transmittance variations of less than 0.5% over large areas of the filter using a 4mm diameter beam. This is at least a factor of five better than typical results seen on earlier filters.

These filters helped make possible the fine intercomparison results between NPL and the PTB BESSY electron storage ring reported in Applied Optics by Fox, Key, Riehle, and Wende. In an experiment similar to one conducted earlier by NBS, they intercompared a silicon/filter radiometer, which had been calibrated against their electrically calibrated cryogenic radiometer, to the predicted spectral radiant flux from the BESSY ring. The experiment was performed at 676 nm and 799 nm, with an agreement of +0.13% and -0.10%, respectively, and a combined uncertainty of 0.3%.

LIDAR Simulator

Fowler and Tobin, working with Geist, finished setting up the LIDAR simulation facility described last year, in suport of the NASA Langley Research Center's Differential Absorption LIDAR (DIAL) program. The device employs a computer controlled acousto-optical modulator to generate a signal on a laser beam selected from a variety of available and/or user programmable waveforms. Using transient digitizers, the device can determine the linearity of detectors under various transient responses, such as $1/(\text{time})^2$. This is important to determine the influence of such effects as ground return pulses on detectors used in LIDAR measurements. NASA Langley will oversee the operation of the facility in Hampton, VA, when completed.

Radiometric Measurement Services Group (D.A. McSparron)

This Group provides a firm measurement base for the Nation's optical radiation community (defense and aerospace, instrument manufacturers and commercial calibration laboratories, lighting and photographic industries, research institutions, etc.). To accomplish this objective, the Group:

(1) Maintains measurement scales and provides, improves and extends NBS calibration services for the basic pyrometric, radiometric, and photometric quantities: radiance temperature, spectral radiance, spectral irradiance, detector spectral responsivity, luminous intensity, luminous flux, and color temperature.

(2) Engages in activites such as intercomparisons, measurement assurance programs, intermediate laboratory support programs, consultations, and ad hoc experiments that will insure that measurements made in laboratories outside NBS have acceptable levels of accuracy.

Calibration Services

Direct calibration billings increased by 3.5%, but directly funded calibration work for other government agencies decreased by 30% due to budgetary cut-backs. The combined effect was a decrease in calibration volume of 6%.

Walker implemented the Saunders-Shumaker sphere technique for realizing the NBS scale of spectral irradiance on FASCAL. This method replaces the previous lamp-mirror image system with the exit port of a water-cooled averaging sphere. The new system eliminates the tedious alignment-stabilization-realigment measurement sequence required by the old system. Utilizing this sphere technique, Walker extended the spectral irradiance scale to cover the spectral region from 1600 nm to 2400 nm. Type FEL, 1000-watt quartz-halogen lamps are presently available calibrated from 250 nm to 2400 nm as a special test. This extended spectral range will be available on a routine basis early next fiscal year.

Documentation

A major part of the Group's effort this year has been devoted to preparing complete documentation of the various calibration services offered. This is part of a Bureau-wide effort to document all NBS calibration activities. The documents prepared addressed the quantities measured, services offered, equipment and procedures used, and particular attention was paid to the preparation of complete uncertainty statements. The following calibration areas were addressed: pyrometry (William Waters, Walker, and Albert Hattenburg), spectral radiance (Walker, Saunders, and

Hattenburg), spectral irradiance (Walker, Saunders, John Jackson, and McSparron), photometry (Robert Booker and McSparron), and detector spectral response (Zalewski).

Intercomparisons

At the 1982 meeting of the Consultative Committee on Photometry and Radiometry (CCPR) plans were formulated for an international intercomparison of the photometric units of luminous intensity and luminous flux. These intercomparisons are of particular interest, since they are the first attempt to evaluate quantitatively the effects of the recent redefinition of the photometric units. During the year, NBS completed its measurements and received preliminary results of the intercomparison from the International Bureau of Weights and Measures. The indicated range of agreement for both quantities is about 2%. The next meeting of the CCPR will take place in October, 1986 and worldwide results will be available at that time.

The visit by Schanda presented an opportunity to compare the NBS detector-based radiometric scales with the source-based scales. Schanda brought a $V(\lambda)$ corrected silicon detector that had been manufactured and calibrated in Hungary. This detector was calibrated for absolute spectral response on the NBS spectral response comparator. It was then calibrated with the NBS working group of luminous intensity standards. The agreement was slightly better than 0.5%. Comparison with the Hungarian scales awaits remeasurement of the detector.

Calibration Facilities Upgrade

Waters is implementing the Jeffery Tapping design of a new photoelectric pyrometer for performing radiance temperature calibrations. This instrument will replace an earlier facility in realizing the International Practical Temperature Scale (IPTS) above the gold point. The new pyrometer employs refractive optics, an extended-red photomultiplier detector, and interference filters which restrict the bandpass to about 1 nm. External vacuum tungsten strip-lamps are used to reproduce small multiples of the gold-point spectral radiance rather than the internal lamp used previously. The detector is operated under measured linear conditions in realizing higher multiples of the gold-point spectral radiance, making the use of absorbing glasses unnecessary. The new pyrometer is presently in operation as a comparator for calbration ribbon-filament tungsten strip-lamps from 800°C to 2300°C at 655 nm. In the near future, a gold-point blackbody will be added to the facility to permit independent temperature scale realizations.

Considerable progress has been made in the modernization of the luminous intensity and color temperature facilities. Certain components of the present facilities are over 60 years old and replacement parts must be hand machined on a custom basis. This causes delays and sometimes forces compromises. Booker has designed a replacement for the current photometric bench. The new facility is based on a double rail and carriage system with Charles Popenoe-designed goniometric lamp mounts. These components, structural hardware, and new power suplies have been purchased and are ready for assembly. The selenium photocells presently used will be replaced with photopically-corrected silicon photodiodes. An evaluation of initial prototypes has begun. When the new photometric bench is complete it will permit more accurate alignment of sources, detectors and components, and will facilitate better control of the luminous intensity calibration service. Modernization of the color temperature comparator has been undertaken to improve reliability and quality control. Two silicon photodiodes fitted with red and blue filters respectively have been mounted in recessed tubes attached to a 20 cm diameter integrating sphere. Ronald Wilkinson and Booker have begun an evaluation of 3 different instruments based on the red-to-blue ratio principle for transferring color temperature calibrations. The instruments differ in the filters and in the detection systems used. The instruments are a Pritchard telephotometer, the red- and blue- filtered silicon photodiodes, and a photomultiplier with revolving red and blue filters. New instrumentation is expected to be brought on line in the first half of next year.

Spectral Flux Standards

The development of geometrically-total spectral flux standards continues. This program was initiated in response to a request from the lamp manufacturing industry and is being coordinated through the Lamp Testing Engineer's Conference (LTEC). NBS agreed to develop both incandescent and non-incandescent standards of geometrically total spectral flux to ensure the accuracy of the industry-derived photometric scales for high-intensity discharge lamps. Ward and Bruening have been setting up the equipment to be used for measuring the goniometric distribution of the lamps. Special lamps have been purchased to serve as incandescent standards and they are being further modified to make them suitable for measurement. Professor He has completed the spectral characterization of a large number of commercially available 400-watt high-pressure sodium lamps. From these, he has selected a group of 12 lamps to be used as the non-incandescent standards.

Photometric Research

Bruening has expanded the work on detector-based filter radiometry to include the use of 100% quantum efficient silicon photodetectors with interference filters to realize a luminous intensity scale. A detector-based scale is an alternative to the present source (blackbody) based scale. The agreement in luminous intensity values obtained form these two bases ranges from +0.5% to -0.1% for the 7 lamps tested.

Ohno completed his project on alternatives to goniometry for generating geometrically-total flux standards. Last year, through computer simulation, the theory of the integrating sphere was extended to include asymmetrical baffle positioning as well as taking account of the effects of multiple baffles. More recently, this theoretical work has been experimentally verified. Four minature lamps were calibrated first by the traditional goniometric method on a small instrument built specially for this purpose by Ohno. They were then calibrated in a sphere configured as indicated by the computer simulations, against a spectral irradiance standard operated external to the sphere. The agreement between the two methods was better than 0.5%. This work verifies the feasibility of realizing geometrically total flux scales without recourse to distribution photometry.

INVITED TALKS

Division 534, Radiometric Physics

Hsia, J.J., "National Scales of Spectrometry in the U.S.", Joint UVSG/CORM Conference on Spectrometry, Oxford University, Oxford, England, September 14-17, 1986.

Mavrodineanu, R., "Chemical Standards for Calibration Purpose", Joint UVSG/CORM Conference on Spectrometry, Oxford University, Oxford, England, September 14-17, 1986, in collaboration with CIE.

McSparron, D.A., "Radiometric Calibration Services of the National Bureau of Standards", Satellite Calibration Workshop, Phoenix, Arizona, March 1986.

McSparron, D.A., "Radiometry Measurement Capability at NBS", 1986 Conference on Precision Electromagnetic Measurements, June 1986.

Mielenz, K.D., "Fluorescence Spectrometry in Analytical Chemistry and Science", Joint UVSG/CORM Conference on Spectrometry, Oxford University, Oxford, England, September 14-17, 1986.

Schaefer, A.R., "Tunable Dye Laser Spectrometry", Joint UVSG/CORM Conference on Spectrometry, Oxford University, Oxford, England, September 14-17, 1986.

Walker, J.H., "Realization of Spectral Radiance and Spectral Irradiance Scales at NBS", September 1986, Physikalisch-Technische Bundesanstalt, Braunschweig, West Germany.

Zalewski, E.F., "Absolute Photon Flux Measurements", Department of Physics Seminar, Towson State University, March 1986.

Zalewski, E.F., "Interpolation of Silicon Photodiode Quantum Efficiency as an Absolute Radiometric Standard", 1986 Conference on Precision Electromagnetic Measurement, June 1986.

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Division 534, Radiometric Physics

Cohen, J., "Introduction to Fourier Transform Spectoscopy", NBS IR 86-3339, March, 1986.

Geist, J., "Nyquist Noise in Current Carrying, Non-linear Circuit Elements", Applied Phys. or Proc. of IEEE

Geist, J., Zalewski, E. F., Tong-Boa, Li., Province, S., "The Quantum Yield of Silicon in the Near-Ultraviolet", Phys. Rev. Lett.

Geist, J., "Silicon Photodiode Physics as a Basic for Accurate Radiometry", 1985 International Conference on Solid-State Sensors & Actuators

Kostkowski, H., Lean, J., Saunders, R.D., and Hughey, L., "Comparison of The NBS SURF and Tungsten Ultraviolet Irradiance Standards", Applied Optics, October 1986.

Mickelson, M. E., Larson, L. E., Fowler, J., "Radiometric Calibration Procedures Using the NBS MARBLE Electronics Package", NBS Technical Note.

Saunders, R.D. and Shumaker, J.B., "Applied Function of a Prism-Grating Double Monochromator", Applied Optics, October 15, 1986.

Saunders, R. D., Shumaker, J. B., "Studies of the Apparatus Function of a Prism-Grating Double Monochromator", Applied Optics.

Schaefer, A.R., Saunders, R.D., and Hughey, L.R., "Intercomparison Between Independent Irradiance Scales Based on Silicon Photodiode Physics, Gold-point Blackbody Radiation, and Synchrotron Radiation", Optical Engineering 25, 892, (July, 1986).

Snyder, J.J., "Laser Heterodyne Densitometer", Proceedings of the Conference on Lasers and Electro-Optics.

Weidner, V. R., Mavrodineanu, R., Eckerle, K. L., "Sintered Mixture of Phosphors in Polytetrafluoroethylene Resin for Fluorescence", Appl. Opt. 25, 832 (1986).

Weidner, V., Hsia, Eckerle, Exploratory Research in Reflectance and Fluorescence Standards at the National Bureau of Standards, Optics News (Published by the Optical Society of America).

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Weidner, V. R., Mavrodineanu, R., Mielenz, K. D., Velapoldi, R. A., Eckerle, K. L., and Adams, B., Holmium Oxide Solution Wavelength Standard form 240 to 640 nm- SRM 2034, NBS Special Publication 260-102, 1-56, July 1986.

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Division 534, Radiometric Physics

Booker, R.L. and McSparron, D.A., Photometric Calibration Procedures, 1986, NBS Special Publication SP 250-16.

Bruening, R.J., Spectral Irradiance Scales Based on Filtered Absolute Silicon Photodetectors, Applied Optics.

Cohen, J., Fundamental and Applications of Infrared Thermography for Nondestructive Testing. A chapter of a book.

Eckerle, K.L., Hsia, J.J., Mielenz, K.D. and Weidner, V. R., Regular Spectral Transmittance Measurements: Documentation and Description of Services, (WERB approved) NBS Special Publication SP 250-6.

Fowler, J., Belzer, B., Water Bath Black Body Operating Instructions, NBS Technical Note.

Geist, J., Fowler, J.B., A Water Bath Blackbody for the 5 to 60 Celsius Temperature Range: Performance Goal, Design Concept and Test Results.

Geist, J., Blocked Impurity Band IR Detector Self-Calibration: Proposal, Applied Optics.

Geist, J., Nofzigar, M.J., Olsen, G.H., Feasibility of Detector Self-Calibration in the Near Infrared, Digest of Technical Papers Conference on Precision Electromagnetic Measurements 1986.

Geist, J., Photodiode Operating Mode Nomenclature, Applied Optics.

Kostkowski, H. J., Lean, J. L., Saunders, R. D., Hughey, L. R., Comparison of the NBS SURF and Tungsten.

McSparron, D., Tibbits, T., Krizek, D., Spectral Effects on the Use of Photon Flux Sensors for Measurement of Photosynthetic Photon Flux in Controlled Environments (in press).

Popenoe, C.H., and Yokley, C.R., Manual of Construction and Control of a Heatpipe Blackbody Source (Sodium and Mercury) Manufactured for the Air Force by NBS.

Saunders, R.D., Shumaker, J., and Walker, J.H., Spectral Irradiance Scale, Metrologia

Schaefer, A.R., and Fox, N.P., Tunable Dye Laser Spectrometry, Proceedings of Advances in Standards and Methodology in Spectrophotometry, Oxford, 1986.

Division 534, Publications in Preparation (cont'd)

Snyder, J., Helmcke, Morinaga, Mensing, Glaser, New Ultra-High Resolution Dye Laser Spectrometer Utilizing Passive Reference Resonator, Proceedings from the PEM.

Walker, J.H., Saunders, R.D., and Hattenburg, A.T., The NBS Scale of Spectral Radiance, (being submitted to Metrologia, WERB approved).

Walker, J.H., Saunders, R.D., and Hattenburg, A.T., Spectral Radiance Calibration at NBS, (Calibration Documentation), WERB approved, SP 250-1

Walker, J.H, Saunders, R.D., Jackson, J.K., and McSparron, D.A., Spectral Irradiance Calibration at NBS, NBS Special Publication SP 250-20.

Waters, J., Walker, J.H., and Hattenburg, A.T., Radiance Temperature Calibrations at NBS, (Calibration Documentation), (WERB approved) NBS Special Publication SP 250-7.

Weidner, V.R., A Wavelength Standard for the Near Infrared Based on the Reflectance of Rare-Earth Oxides (in press).

Weidner, V.R. and Hsia, J.J., Spectral Reflectance Measurements: Documentation and Description of Services, (WERB approved) NBS Special Publication SP 250-8.

Weidner, V., A Gray Scale of Diffuse Reflectance for the Wavelength Range 250-2500nm, Letter to the Editor of Applied Optics.

Zalewski, E. F., Gladden W. K., Interpolation of Silicon Photodiode Quantum Efficiency as an Absolute Radmetric Standard, Digest of Technical Papers Conference on Precision Electromagnetic Measurements 1986.

Zalewski, E.F., The NBS Photodetector Spectral Response Calibration Transfer Program, NBS Special Publication SP 250-18.

TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION AND LEADERSHIP

Division 534, Radiometric Physics

Robert Booker

Member, U.S. National Committee of the CIE

Robert J. Bruening

President, National Captial Section of the Optical Society of America Technical Professional Society

Julius Cohen

Member, ASTM E-07 Committee on Nondestructive Testing, Section E-07.10.04 on Infrared Methods.

Kenneth L. Eckerle

Member, ASTM E-13 Committee on Molecular Spectroscopy, Subcommittee E-13.03 on Infrared Spectroscopy, Subcommittee E-13.01 on Ultraviolet and Visible Spectroscopy, Subcommittee E-13.06 on Luminescence.

Jon C. Geist

Member IMEDO 10002 on Photon Detectors.

Albert Hattenburg

Member, CORM technical committee on Array Radiometry.

Jack J. Hsia

Director, Inter Society Color Council.

Assoicate Director, CIE Division 2 on Physical Measurement of Light and Radiation.

Chairman, CIE TC 2-11 Technical Committee on Goniophotometry.

NBS Representative, ANSI PH2 on Photographic Sensitometry and PH2-28 on Densitometry.

Member, ASTM D-1.26 Subcommittee on Optical Properties of Paint, Varnish, Lacquer and Related Products.

Division 534, Technical and Professional Committee Participation and Leadership (cont'd)

Jack J. Hsia (Cont'd)

Member, ASTM E-12 Committee on Appearance of Materials (Spectrophotometry, colorimetry and geometric properties).

Member, ASTM E-13 Committee on Molecular Spectroscopy, Subcommittee E-13.01 on Ultraviolet and Visible Spectroscopy, E-13.03 on Infrared Spectroscopy, and E-13.06 on Molecular Luminescence.

Member, ASTM E-07.03 Task Group for Fluorescent Penetrant Measurement Standards.

Secretary, CORM/NBS Task Force on Spectrophotometry.

Donald A. McSparron

Consultant, CIE Technical Division II on Physical Measurement of Light and Radiation.

Member, ANSI Z311 on Photobiological Safety of Lamps and Lighting Systems.

Member, Illuminating Engineering Society (IES), Testing Procedures Committee.

Member, Lamp Testing Engineers' Conference.

Klaus D. Mielenz

Secretary, U.S. National Committee of the CIE.

Director, CIE Division 2.

Member, ASTM E-13 Committee on Molecular Spectroscopy, Subcommittee E-13.06 on Molecular Luminescence.

Member, IES, Nomenclature, Subcommittee C012.

Vice Chairman, CORM, TASK Force on Spectrophotometry.

Member, IES Committee on Nomenclature.

Member, OSA International Affairs Committee.

Division 534, Technical and Professional Committee Participation and Leadership (cont'd)

Robert D. Saunders, Jr.

Member, ANSI Z311 on Photobiological Safety of Lamps and Lighting Systems.

Member, IES Committee of Photobiology.

A. Russell Schaefer

Member, CIE TC2-06 Technical Committee on Absolute Spectral Responsivity.

Douglas B. Thomas

Member, ASTM Committee E44 on Solar Energy Conversion.

William R. Waters

Member, ASTM Committee E-20 on Temperature Measurement.

Edward F. Zalewski

Chairman, CIE TC2-06 Technical Committee on Absolute Spectral Responsivity.

Member, CIE Committee Div. 02 on Physical Measurement of Light and Radiation.

Member, U.S. National Committee of the CIE.

Member, OSA Ines Medal Award Selection Committee.

JOURNAL EDITORSHIPS

Division 534, Radiometric Physics

Zalewski, E.F., International Advisory Board, Optica Pura y Aplicada

STANDARDS COMMITTEE MEETINGS

Division 534, Radiometric Physics

CORM Directors Meeting, Department of Commerce, January 28, 1986.

USNC Technical Council and Executive Committee Meeting, NBS, March 18-19, 1986.

CCG Meetings, NBS, May 27-30, 1986

STANDARDS WRITING

Division 534, Radiometric Physics

J. Cohen, New Standard Test Method For Minimum Resolvable Temperature Difference for Thermal Imaging Systems, ASTM E-07.10.04 on Infrared Methods. (Approved by Subcommittee Votes, August 1986)

J. Cohen, New Definitions of Terms Relating to NDT by Infrared Thermography. (Approved by Subcommittee Votes, August 1986)

MAJOR CONSULTING AND ADVISORY SERVICES

Division 534, Radiometric Physics

J. Geist and E. Zalewski advised Naval Research Laboratory on the selection of the best photo-sensors to measure laser radiation directed at a spaceborne target: LDEF/ITS Mission.

J. J. Hsia provided consultation to S. Mohan of Indian Institute of Science on specular reflectance measurements of thin films.

J. J. Hsia advised Sol Glicker of NASA Goddard Space Flight Center on developing a goniophotometer to measure bidirectional reflectance distribution function.

J. J. Hsia and V. R. Weidner provided consultation to Roy Berns of The Rochester Institute of Technology on reflectance measurements of NBS supplied gray diffusers.

J. J. Hsia provided consultation to Roger McCleary of Eastman Kodak on diffuse transmittance measurement methods.

D. A. McSparron served as a consultant to the Growth Chambers and Controlled Environments Working Group of the American Society for Horticultural Science on optical radiation measurements in plant growth chambers.

D. A. McSparron and J. H. Walker provided consultation and advice to representatives of Negretti Aviation on appropriate measurements and standards to establish traceability of their infrared pyrometric measurements for the jet turbine industry.

V. R. Weidner provided consultation to Sadegh Siahatgon and Sandra Holder of Naval Sea System Command on specular reflectance measurements on multilayer mirrors.

E. Zalewski provided consultation to the Countermeasures Branch of the U.S. Army Tank Automotive Command, on photodetector linearity in the near infrared region and associated transmittance measurement problems.

STANDARD REFERENCE MATERIALS

Division 534, Radiometric Physics

1. SRM 1001, X-Ray Film Step Tablet

   For calibration of optical densitometers and similar equipment used in the photographic, graphic arts, and x-ray fields. Certified for optical densities from 0 to 4.

2. SRM 1008, Photographic Step Tablets

   For calibration of optical densitometers and similar equipment used in the photographic and graphic arts fields. Certified for optical densities form 0 to 4.

3. SRM 1010a, Microcopy Resolution Tests Charts

   For determining the resolving power of microcopy systems.

4. SRM 2061, Reflection Step Tablets

   For calibration of reflection densitometers and similar equipment used in the photographic and graphic arts fields. Certified for optical density from 0 to 2.

5. SRM 2019 and 2020, White Ceramic Tile for Directional-Hemispherical Reflectance from 350 to 2500 nm.
   SRM 2021 and 2022, Black Porcelain Enamel for Directional-Hemispherical Reflectance from 280 to 2500 nm.
   SRM 2015 and 2016, White Opal Glass for Directional-Hemispherical Reflectance from 400 to 750 nm.

   For use in calibrating the reflectance scale of an integrating sphere reflectometer.

6. SRM 2003b, First Surface Aluminum Mirror for Specular Reflectance from 250 to 2500 nm.
   SRM 2011, First Surface Gold Mirror for Specular Reflectance from 600 to 2500 nm.
   SRM 2023, 2024, and 2025 Second Surface Aluminum Mirror for Specular Reflectance from 250 to 2500 nm.

   For use in calibrating the photometric scale of specular reflectometers.

7. SRM 2009, 2010, 2013, 2014 Didymium-Oxide glass as Wavelength Standards between 400 and 760 nm.

Division 534, Standard Reference Materials (cont'd)

8. SRM 2034 Holmium oxide in Perchloric Acid Solution as Wavelength Standards between 241 and 640 nm.

9. SRM 1920 Near Infrared Reflectance Wavelength Standards from 740-2000 nm. (In preparation).

MEASUREMENT ASSURANCE SERVICES

Division 534, Radiometric Physics

1. Transmittance MAP Service

   Provides a means for a laboratory to assess the accuracy of its spectral transmittance measurement capabilities from 92% to 0.1% in the visible region.

2. Retroreflectance MAP Service for Coefficient of Luminous Intensity

   Provides a means for a laboratory to assess the accuracy of its coefficient of luminous intensity measurement capabilities for bead sheeting and prismatic cube-corner retroreflectors and to assess the conformity to the spectral specification of its retroreflectometers.

CALIBRATION SERVICES PERFORMED

Division 534, Radiometric Physics

Type of Service	Customer	SP250	Number of tests	
Pyrometry		7.4 A thru G		40
	Defense & Aerospace		25	
	Instrument & Cal labs		6	
	Lighting & Photography		3	
	Electrical & Materials		6	
Spectroradiometry		7.5 A thru J		23
	Defense & Aerospace		8	
	Instrument & Cal labs		8	
	Lighting & Photography		1	
	Foreign		3	
	Electrical & Materials		3	
Photometry		7.7 A thru R		32
	Defense & Aerospace		17	
	Instrument & Cal labs		6	
	Lighting & Photography		6	
	Foreign		2	
	Electrical & Materials		1	
Spectrophotometry		7.8 A thru I		24
	Defense & Aerospace		7	
	Instrument & Cal labs		7	
	Lighting & Photography		2	
	Electrical & Materials		8	
				119

TRIPS SPONSORED BY OTHERS

Division 534, Radiometric Physics

J. J. Hsia, Laboratory visits to Hungary, partially sponsored by Protocol Agreement between NBS and Hungarian National Office of Measures, Budgapest and Institute of Technical Physics in Hungarian Academy of Sciences, Budapest.

E. F. Zalewski, sponsored by the U.S. Army Tank Command, Countermeasures Branch, travel to Warren, Michigan to consult on photodetector linearity measurements, February 24-26, 1986.

SPONSORED SEMINARS AND COLLOQUIA

Division 534, Radiometric Physics

Dr. W. Borucki, "Photometric (Radiometric) Search for other Solar Systems", Radiometric Physics Division Photodetector Physics and Metrology Group Seminar, October 1985.

TECHNICAL ACTIVITIES

Division 535, Radiation Source and Instrumentation

CW Accelerator Research (Microtron) (P. H. Debenham)

The joint NBS-Los Alamos project of "Research on CW Electron Accelerators Using Room-Temperature RF Structures" began seven years ago with the goal of developing a technology base for cw electron accelerators. Many significant technical advances have been made as a part of this project, which is funded by DoE. Among the earliest contributions was the unexpected experimental discovery that the disk and washer accelerating structure sustains transverse deflecting modes that make it unsuitable for use in a recirculating accelerator.[1] We then developed a reliable room temperature accelerating structure with a high cw voltage gradient.[2] This structure has been adopted with minor modifications by the University of Illinois for their proposed 450 MeV cascaded microtron.[3] The structure also provides an important part of the engineering data base for high-gradient cw rf structures for applications outside nuclear physics being pursued at Los Alamos and elsewhere.

Our 100 keV beam line with its unique chopper-buncher system has been adopted by two microtron laboratories (University of Illinois and Mainz University) and will be used at CEBAF. Our unique design for racetrack microtron (RTM) end magnets is an important advance in achieving high field uniformity over a large area. The University of Illinois has had exact copies of our end magnets built for their microtron. Our beam profile scanner design has been sent to many laboratories, and is being used by The University of Saskatchewan and MIT.

An essential part of this research project is the design, construction and operation of a demonstration accelerator. The demonstration accelerator, as shown in Figure 1, consists of a 5 MeV injector feeding a racetrack microtron. In the microtron, a pair of 180° end magnets recirculate the beam through a 12 MeV linac 15 times for an energy gain of 180 MeV. The control system for the demonstration accelerator is fully

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[1] L.M. Young and J.M. Potter, "Deflecting Modes in the DAW Structure for the Racetrack Microtron," Los Alamos National Laboratory, Accelerator Technology Division, Group AT-1 memorandum No. AT-1:82-59 (March 17, 1982).

[2] L.M. Young and J.M. Potter, "CW Side-Coupled Linac for the Los Alamos/NBS Racetrack Microtron," IEEE Trans. Nucl. Sci. NS-30, 3508 (1983).

[3] L.S. Cardman et al, "Nuclear Physics Research with a 450 MeV Cascade Microtron," unpublished (1986).

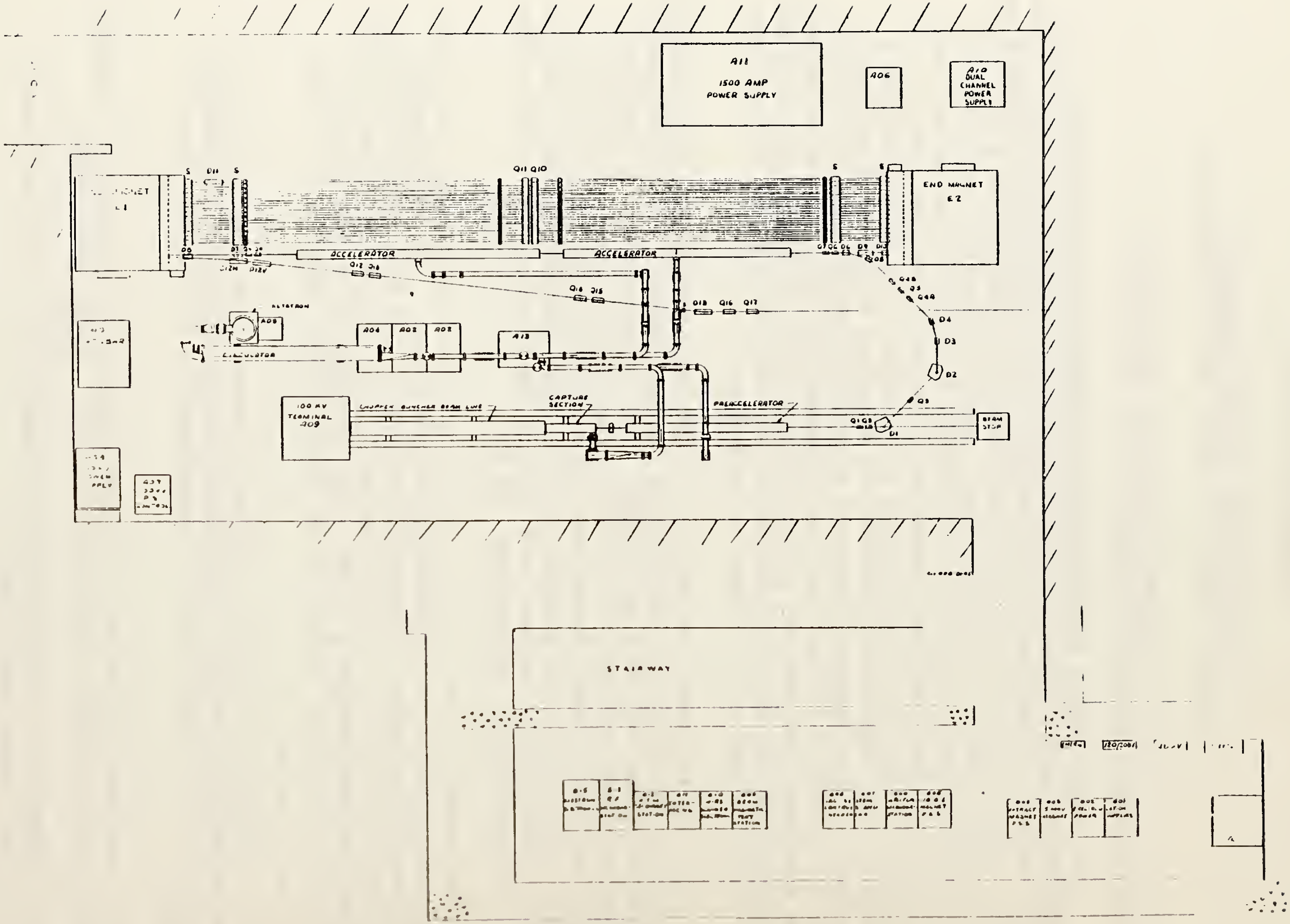


Figure 1   Plan view of the demonstration accelerator.

functional. The rf power system is unique and simple: a single, 450 kW cw klystron powers four accelerating sections with independent phase and amplitude control of each section. The rf system is in place and has been operated to power the 5 MeV injector linac. It is temporarily inoperative while the klystron power supply is modified for reliable operation. The injector is complete and has produced a 5 MeV cw electron beam with an energy width of 11 keV. Extensive measurements of the injector beam properties will be made as soon as the rf system is again operational. The end magnets have been field-mapped, are aligned, and are ready to operate. The 12 MeV linac is aligned in place between the end magnets, has been vacuum and low-power tested, and will be high-power tested when the rf system is operational.

In the future, this project will continue to make important contributions to science and technology. CEBAF has expressed much interest in several aspects of our project. The performance measurements of our injector are directly applicable to their injector, and CEBAF personnel intend to participate in the measurements. They also plan to gain operational experience on the demonstration accelerator prior to commissioning their accelerator. The project includes measurements of the threshold current for beam breakup (BBU) in the demonstration accelerator early in 1988. The measurements will be used to validate the computer program which is used to calculate the BBU threshold current for CEBAF, and will be available in time to influence design decisions.

The demonstration accelerator, when completed at NBS in mid 1988, will be the only 200 MeV cw electron accelerator in the US and will have the highest cw current and power in the world. Naturally, such a unique facility is attracting a good deal of interest. NBS is committed to supporting a nuclear physics research program based on the RTM and is developing plans for a high energy dosimetry program.

There is also a good deal of interest in using the high power, low emittance beam of the RTM as a free-electron laser (FEL) driver. An ONR-funded study concludes that the RTM becomes an excellent FEL driver if the present thermionic cathode electron gun is replaced with a laser-driven photocathode for higher peak current. Modification of the RTM for FEL operation will not be part of the present project.

In order to have three simultaneous cw electron beams with different currents, CEBAF needs an injector that can modulate the beam current in three successive micropulses with good dynamic range. A photocathode injector can meet this requirement, and CEBAF is very interested in having us develop a prototype photocathode system for them and test it with the RTM.

In summary, this project has made many significant contributions and promises to make many more. In the remainder of this report we describe in detail the technical accomplishments of the project in FY 1986. This year we produced a 5 MeV electron beam for the first time with the demonstration accelerator injector. The properties of this beam appear to be excellent. Definitive injector beam measurements have been pushed to the beginning of FY 1987 by the need to modify the klystron power supply in the rf system for reliable operation.

Meanwhile, preparations have been underway for transporting the injector beam to the RTM for one and two passes through the RTM linac. Components of the 5 MeV beam transport line and the RTM linac axis beam line are in procurement. The RTM linac was installed, aligned, and connected for rf power. The field of the second end magnet was mapped and found to be satisfactory, and both end magnets were aligned. The control system has been modified for improved reliability and is being expanded for one- and two-pass RTM operation. STRACE, the RTM raytracing program, was improved for better accuracy and was used to find a linac-to-end magnet spacing that will give a good longitudinal phase space match between the injector and RTM.

A. Injector

1. Introduction

The RTM injector consists of an electron gun in a 100 kV terminal, a 100 keV beam transport line, a 5 MeV injector linac, and a 5 MeV beam transport line. The performance of the 100 keV stage was measured previously, and in November 1985 the injector linac accelerated a cw beam to 5 MeV for the first time. Repeated failures of the klystron power supply unfortunately prevented operation of the injector linac after November, leaving both development of wirescanners for 5 MeV electrons and definitive measurements of 5 MeV beam properties incomplete. Nonetheless, the 5 MeV beam properties appear to be excellent, judging from spot sizes on viewscreens. The 5 MeV measurements will be resumed as soon as the klystron power supply is operational. Meanwhile, we are procuring all components needed to complete the 5 MeV beam transport line, which will be assembled immediately after completion of the injector beam measurements.

2. Injector Beam Tests

During the fall of 1985, the 5 MeV injector was operated on a schedule of three two-week periods between periods of construction in the RTM room. Preliminary injector beam measurements were done using the first stage of the 5 MeV transport system, shown in Figure 2. During these runs, the phase and amplitude controls of the high power rf system were de-bugged, the injector linac was conditioned under power, and the computer-controlled conditioning system brought into operation. In addition, the wirescanner and rf beam monitors were tested, with the beam-induced signals being transported to the main control room through a

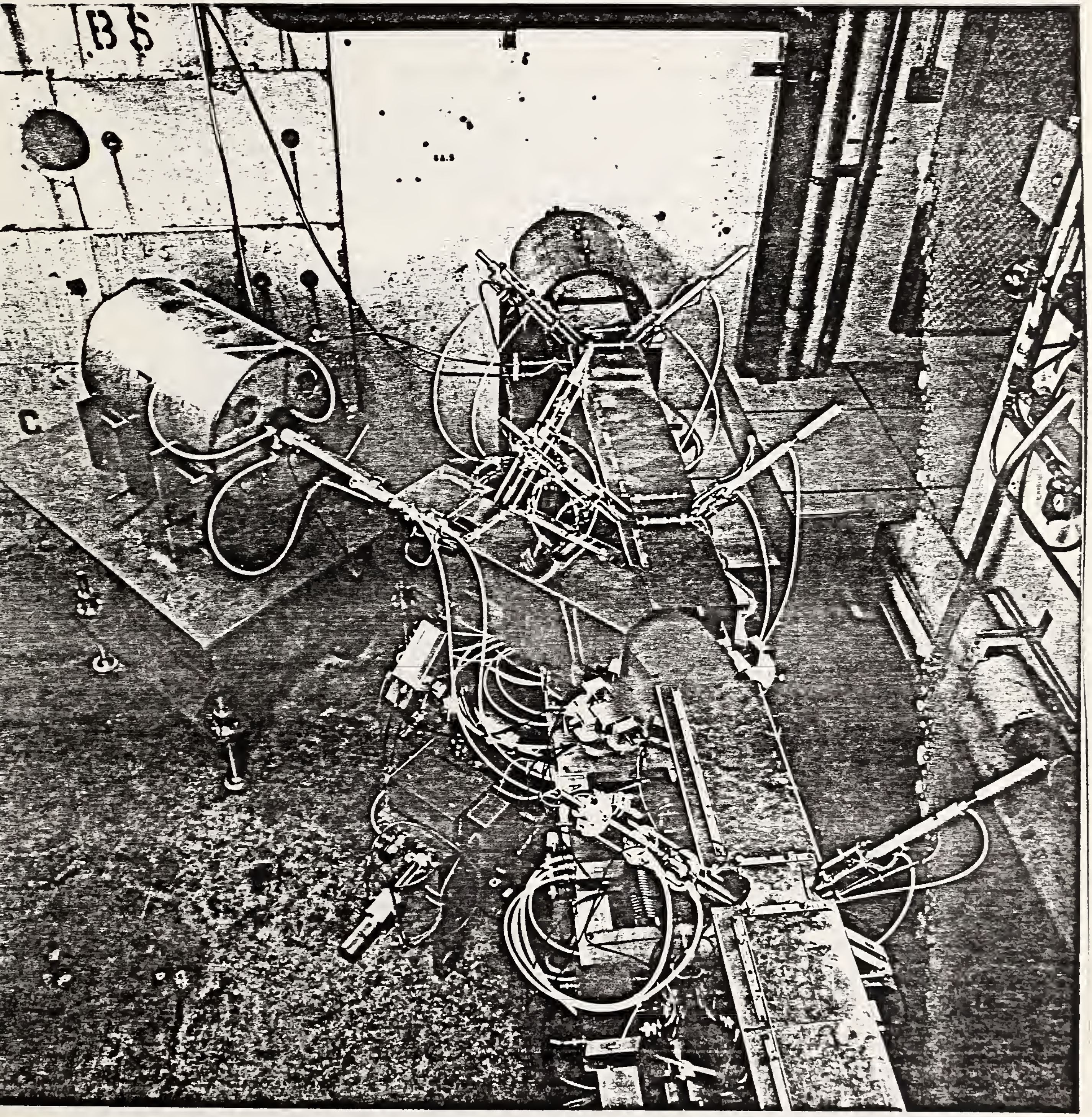


Figure 2 Photo of the first stage of the 5 MeV beam transport system as viewed from above the exit of the injector linac. The beamstop and viewscreen in the 45° beam line are in a temporary position for the injector beam measurements.

computer-controlled remote coaxial switch for the first time. After optimizing the capture section and the preaccelerator phases with a pulsed beam, we obtained a 5 MeV pulsed beam. After conditioning the linac further with a low-current cw beam, we obtained a low-current, 5 MeV cw beam.

The injector beam tests were begun by first finding the correct phasing of the capture section with respect to the bunched beam, for minimum energy spread at near maximum energy gain, with the preaccelerator off. This condition was determined by using the dispersion in the first 45° dipole magnet (D1) in the 5 MeV transport system. Figure 3 shows the beam spot on a view screen 54 cm from the exit of the magnet. The energy spread, as defined by the width of the beam spot, is reduced by a factor of three when the buncher is turned on with the correct relative phase. The magnetic field required in D1 corresponds to a beam energy of 1.25 MeV.

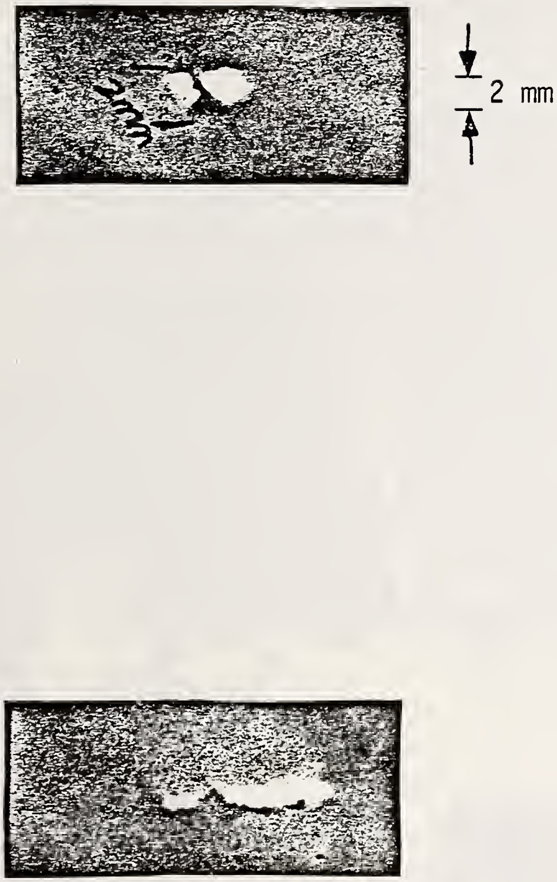
Next, the preaccelerator was conditioned to a level that would sustain a moderate energy gain, and the preaccelerator phase was adjusted to provide the minimum energy spread at near maximum energy gain, by the same technique used for the capture section. From the width of the beam on the viewscreen and the known magnet dispersion, the energy spread was estimated to be 11 KeV. Further optimization, over a range of beam energies, beam current, and buncher amplitude, is planned.

We next began conditioning the linac with a low-current cw beam. On November 8, a 40 μA cw beam was accelerated to 5 MeV and dumped into the 0° beam stop. Further conditioning for acceleration of high-current cw beams was underway when, on November 18, the klystron power supply failed. After it is repaired, injector beam measurements will resume.

3. 5 MeV Transport and RTM Axis Beam Lines

After the injector beam measurements have been completed at the end of FY86, the remaining section of the 5 MeV beam transport line and RTM axis beam line will be assembled in order to begin one-pass and two-pass operation of the RTM. The 5 MeV transport line is shown in Figure 4. Detailed design of all magnets for these beam lines was completed in this year, and all magnets and power supplies are either on hand or in procurement. An assembled 30° dipole magnet is shown in Figure 5. All wire and cable needed to connect these beam lines to the power supplies and the control system are on order or in hand.

Because most of these magnet designs are tightly constrained, we have ended up doing the steel design and fabrication in house. Coils were fabricated to our specifications by vendors through competitive bidding. All magnets will be mapped prior to installation.



(a) Buncher on

(b) Buncher off

Figure 3 Image of the 1.25 MeV beam spot on a viewscreen 54 cm from the 45° exit of dipole magnet, D1, (a) with the buncher on and (b) with the buncher off. The irregularities in the spot shape are due to fiducial marks on the viewscreen. Momentum dispersion is horizontal in these photos.

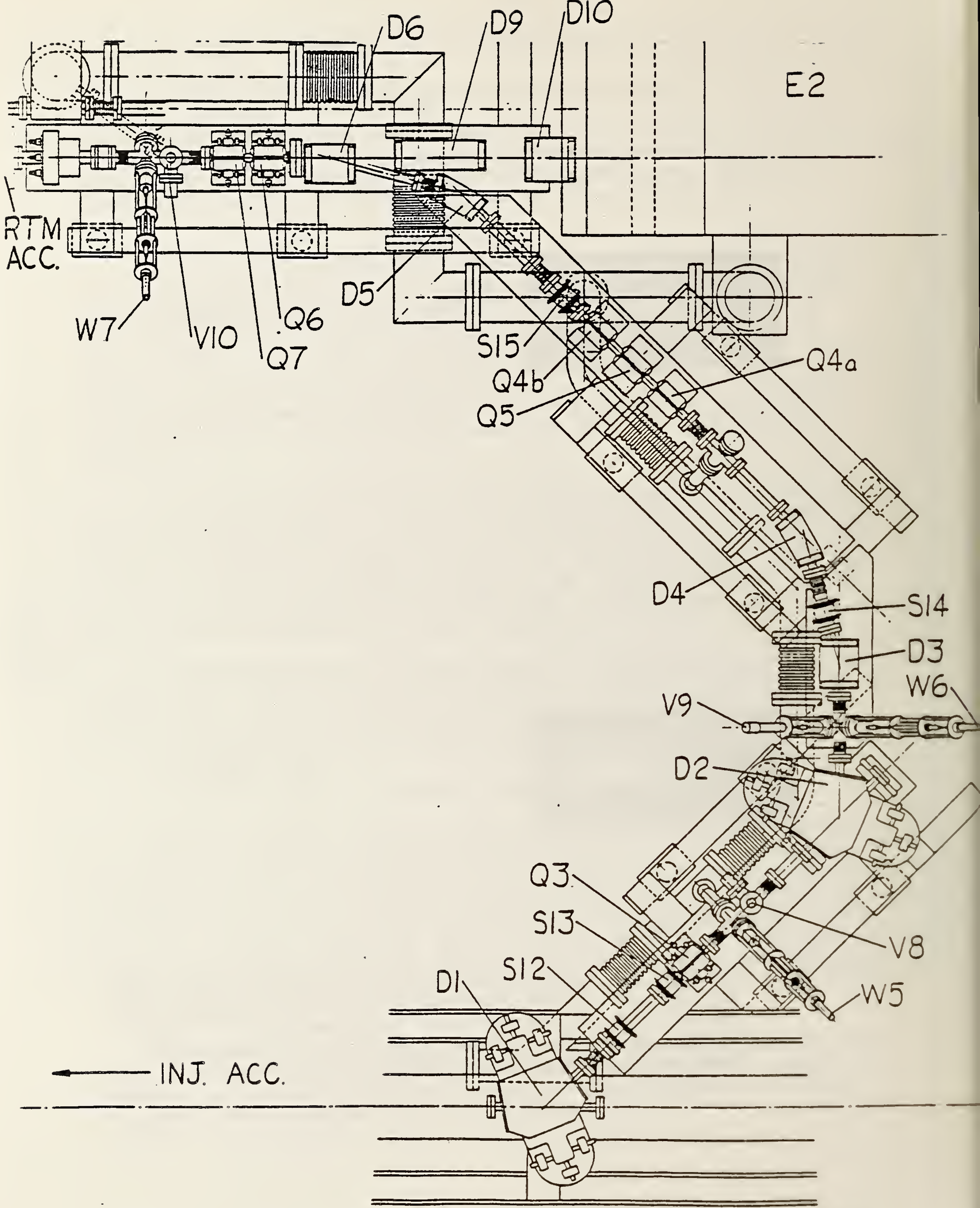


Figure 4 Plan view of the 5 MeV beam transport line from the injector to the RTM.

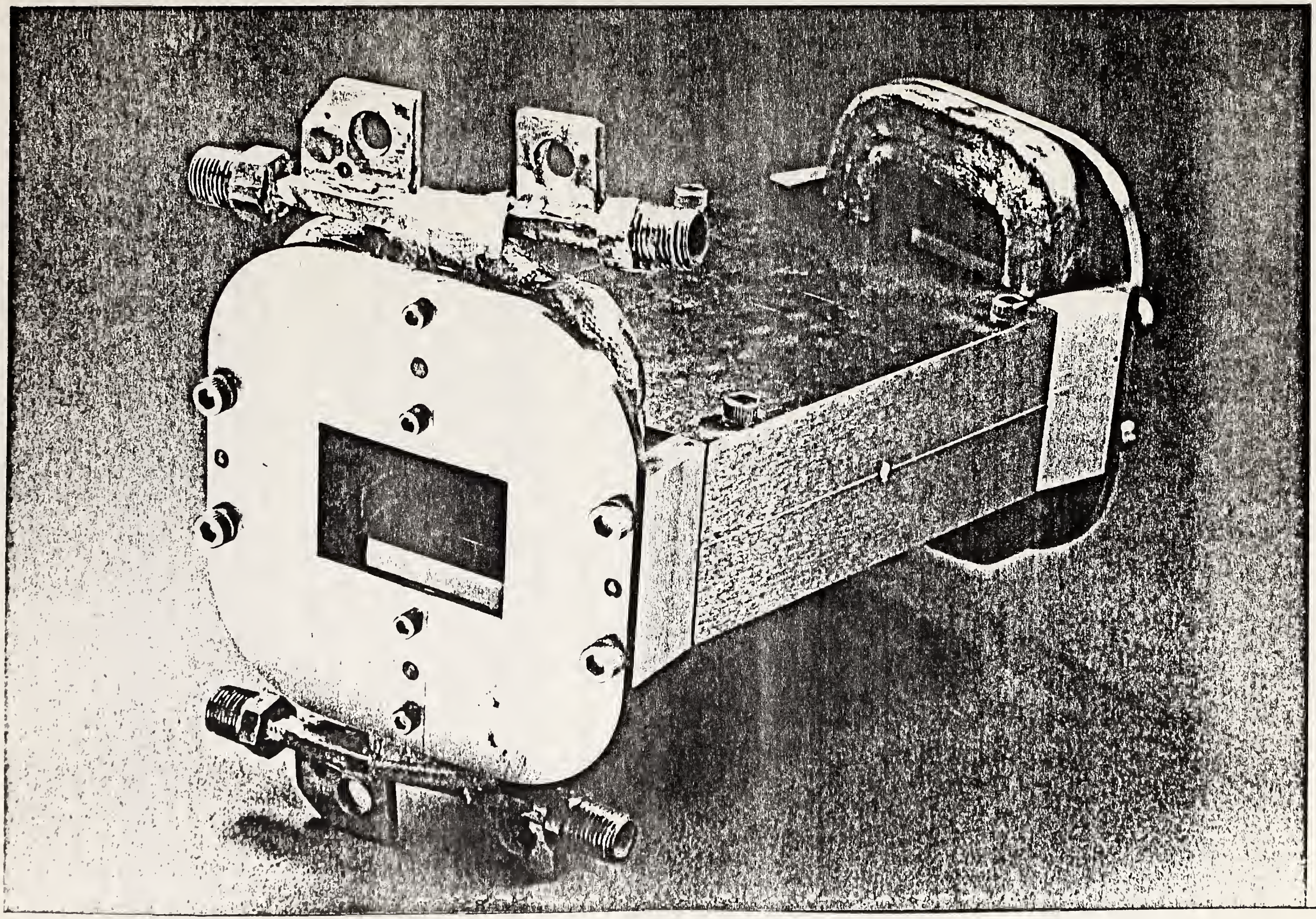


Figure 5 30^{o} Dipole magnet D4 for 5 MeV beam transport line. The magnet is shown actual size.

Vacuum chambers for the 15° and 30° magnets, D3, D4 and D5 will consist of curved sections of 1" OD seamless, 300-series stainless steel tubing. Permeability measurements on this material showed that bending to the required radii had no measurable effect on the original permeability of less than 1.05. Rectangular cross sections are required for the vacuum chambers in the remaining dipole magnets on these beam lines. To avoid distortions in the dipole magnetic fields, the rectangular vacuum chambers will be made of copper, brazed to non-magnetic stainless steel flanges or adapter rings.

B. Microtron

1. Introduction

The microtron consists of a 12 MeV linac, two end magnets, beam lines to recirculate the beam through the linac, and a beam line to extract the beam and measure its properties. In FY 1986 we concentrated on preparing the microtron for one-pass and two-pass operation, which requires everything but the return beam lines and the extraction beam line. The 12 MeV linac was installed, aligned, vacuum tested, and connected to the rf system. The second end magnet was mapped and found to have acceptable field quality, and both end magnets were aligned. Both the main power supply for the end magnets and the power supply for the active field clamps passed final acceptance tests at NBS. All magnets on the linac axis beam line are in procurement, and many vacuum components of the microtron are on hand.

2. End Magnet Field Mapping

The end magnets were designed to generate a uniform field in the operating range 0.8 T to 1.2 T with a field uniformity such that the phase error (i.e., path length error) on every orbit is less than 2°. The field of end magnet E1, presented in last year's annual report, is considerably more uniform than required. The field of end magnet E2 was mapped in October 1985, with the results shown in Figure 6. The orbit-averaged spatial field variation in magnet E2 is roughly four times greater than E1, yet the fields of the two magnets together produce a calculated phase error of less than 2° on every orbit. This means that the RTM will operate over the design end magnet field range of 0.8 T to 1.2 T with the end magnets as built, without shimming.

The reason for the different field quality of these two magnets is not obvious. The end magnet vendor first delivered magnet E2, then two magnets of the same design and specifications to the University of Illinois, and finally magnet E1. The field quality of the University of Illinois magnets is intermediate between that of E1 and E2. Since all four magnets were made to the same specifications, the improvement in field uniformity with production order can probably be attributed to the vendor's increased experience with time.

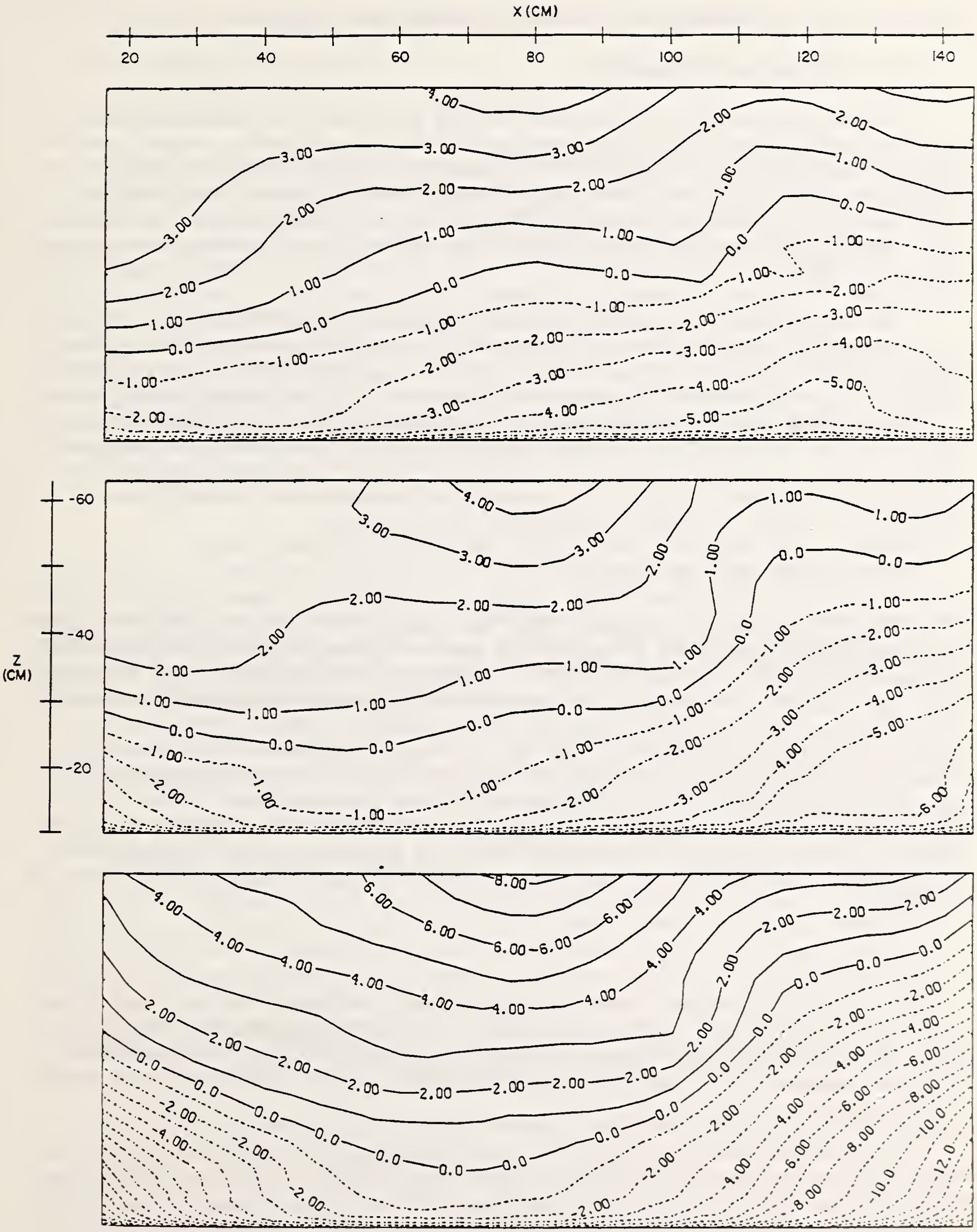


Figure 6 Contour plots of $(\Delta B/B_0) \times 10^4$ as measured for end magnet E2. From top to bottom, B_0 is 0.8, 1.0, and 1.2T. Negative contours are shown as broken lines.

3. End Magnet Alignment

The most stringent requirement on the alignment of the end magnets is that any misalignment must be compensated with the steering magnets on the return beam lines. The strength of these return-line steering magnets is limited to 125 gauss·cm by the requirement that the power supply noise (typically 10^{-3}) should make a negligible contribution to beam emittance. This requirement limits the tolerable end magnet misalignment to no more than 0.05 mrad in all planes.

The end magnets have been aligned with the required accuracy. The poles of both magnets were leveled using a theodolite and a back-lighted, high precision optical target which could be moved over the entire pole surface. Our measurable accuracy was ±25 μm (±.001 in) everywhere, which is three times better than needed. Perpendicularity to the linac axis beam line and parallelism between the two magnets were achieved using a theodolite and an optically-flat, front-surface, 8" diameter mirror and autocollimating over 12 m. Our accuracy of measurement was ±125 μm (±.005 in), which is many times better than needed.

4. 12 MeV Linac Alignment

The 12 MeV linac has been installed and aligned in the RTM room. The alignment was done using a theodolite and a lighted optical target, which was moved through the center bore of the structure one cell at a time. With this method, we found a ±0.5 mm cell-to-cell misalignment from manufacturing which effectively reduces the through diameter from 10 mm to 9 mm. In order to further refine our measurements we set up a 1 cm diameter alignment laser on the nominal beam line. The collimated beam measured on a target at the output end of the structure was 9 mm. This was further collimated with a 0.5 mm diameter hole on the structure centerline and this was autocollimated with the mirror used for magnet alignment. The laser light was not visible around the edges of the 0.5 mm diameter.

5. Extraction Hole

A ten inch diameter hole for the extraction beam line has been drilled from the north wall of the RTM room into the magnet room. The alignment requirement of ±2 inches was easily exceeded. The hole has been plugged temporarily to allow operation of the L-band linac with the RTM room occupied.

C. RF System and Structures

1. Introduction

During FY 1986, the rf system was completed with the shipment of the 12 MeV RTM linac from Los Alamos to NBS and its installation in the RTM room. Cooling water and waveguide connections were also completed. Beam tests performed on the injector linac confirmed the calculations and measurements made at Los Alamos of the effective shunt impedence (ZT^2) of the side-coupled structure. The RF control system has operated very reliably and is currently being completed to include the 12 MeV linac and its associated temperature controls, power monitors, and waveguide power splitters and phase shifters. Unfortunately, problems have continued with the klystron power supply. However, a replacement of improved design for the troublesome part, the variable transformer, has been ordered and is scheduled for installation in November 1986.

2. RF Power

The rf power system consists of a 65 kV DC power supply, a 450 kW cw klystron, a crowbar unit, and an rf circulator to protect the klystron from reflected power. The 65 kV DC 16.5A power supplies at Los Alamos and NBS have a history of problems, listed in Table 1. Most of these problems have been corrected either by us or by the power supply manufacturer. However, one component, the variable transformer (PVT), has failed repeatedly and seems to be under-engineered.

The variable transformer is a 13.8 kV line-to-line (8 kV to ground), oil immersed autotransformer design. Its failure mode consists of severe arcing at the sliding brush assembly contacts of the autotransformer, which burns through the transformer windings. After the last failure in January 1986, it was examined by high voltage transmission experts in the Electrosystems Division at the National Bureau of Standards. Their opinion is that the turn- to-turn voltage of the PVT was too high, and that once arcing initiates across the brush assembly the oil breaks down and accelerates the frequency and severity of the arcing, which ultimately destroys the transformer. The power supplies built for our project were among the first to use the 13.8 kV PVT built by this manufacturer. Later units built for the storage ring at Cornell have similar problems. We therefore felt that rebuilding the PVT as before would not solve the problem, as the design is not suitable for such high voltages.

With the assistance of Dr. Wagih Fam, on leave from the University of Halifax, Nova Scotia, Canada where he is the Electrical Engineering Department Chairman, replacement designs for the PVT were sought from both the original manufacturer of the power supply and from other manufacturers of high voltage, high power supplies. Four different technologies were offered by six different companies. These designs used induction voltage

Table 1 Hipotronics 65 kV-16.5 A Power Supplies, February 12, 1986

Los Alamos

Summer 81	Power supply installed.
December 81	Power supply commissioned, with crowbar modified at Los Alamos. Output voltage ripple is 15%.
Spring 83	New PVT with balancing windings installed. Ripple is reduced to 2%. Original PVT returned to Hipotronics to be modified for NBS.
April 84	PVT failure. Balancing windings moved, shorted. PVT returned to Hipotronics for repair.
Summer 84	Rebuilt PVT installed with reinforced balancing windings. Used successfully for injector linac power tests.
September 85	PVT removed and sent to NBS.

NBS

Fall 81	Power supply installed.
October 83	PVT replaced with former Los Alamos PVT with balancing windings added. Original PVT returned to Hipotronics.
September 84	PVT returned to Hipotronics for reinforcement of balancing windings.
November 84	PVT returned to NBS without modification. Hipotronics claims strength of balancing windings is adequate.
April 85	Power supply turned on for first time.
August 85	PVT failure. Balancing winding for one phase moved, shorted. Main windings for two phases burned through at brush contact. PVT returned to Hipotronics for repair.
October 85	Power supply turned on with Los Alamos PVT installed.
November 85	Los Alamos PVT failed. All main windings burned through at brush contact. PVT returned to Hipotronics for repair.
January 86	Rebuilt NBS PVT installed. Power supply operated for two days before PVT failed.

regulators, multiple tap changing under load transformer-switch assemblies, very large 13.2 kV conventional variable autotransformers with low turn-to-turn voltages, and lower voltage variable transformers used in a bucking mode against the incoming line voltage. It was determined that the first three options would be either too expensive (\$80K - \$150K) and/or take to long to contract, build and install (20 - 60 weeks). The original manufacturer offered to build a bucking transformer design for \$20K. It will consist of:

1. PVT Model 60A260-260Y14
   Input: 2600 V, 3 ϕ, 60 Hz, 690 KVA
   Output: 0-2600 V @ 150 A, Wye Connected

2. Isolation Transformer
   Pri. 13.2 kV @ 690 kVA, 3 ϕ, 60 Hz, Delta Connected
   Sec. 2600 V @ 150 A, Wye Connected

3. Buck/Boost Transformer
   Pri. 1500 V @ 690 kVA, 3 ϕ, 60 Hz, Delta Connected
   Sec. 4600 V @ 50 A

and connected as shown in Figure 7. The manufacturer will connect up the controls and interlocks to be compatible with the existing system. We believe this represents the best solution to be had given the time and money constraints. The manufacturer's reputation for the lower voltage variable transformers is good. Also, as it is a bucking design, the variable transformer is isolated from surges and has only 690 kVA flowing through it rather than 1.2 MVA. The contract was let May 16, 1986, and the replacement unit is scheduled for installation in September 1986.

3. Injector Linac and Controls

The RTM injector linac consists of a 1 m capture section followed by a 2.7 m preaccelerator section. The injector linac has been operated with beam at full voltage (5.0 MeV). Initial beam measurements show that the preaccelerator has an effective shunt impedence (ZT^2) of 93 ± 10% MΩ/m, in agreement with the voltage gradient measurements done at Los Alamos.

The rf control system has operated very well the past year. We have developed an auto conditioning/power turn on program. For normal operation, this program automatically raises the power level in two linac sections from zero to full operating levels in a few minutes. The program raises the forward power and monitors both reverse power and vacuum for each linac. It also varies the frequency of the klystron to allow faster starts when the linac structures are cold and have a higher resonant frequency. The program is invaluable both during rf conditioning and normal power turn-on. The program will be modified so all four linac sections can be run up together.

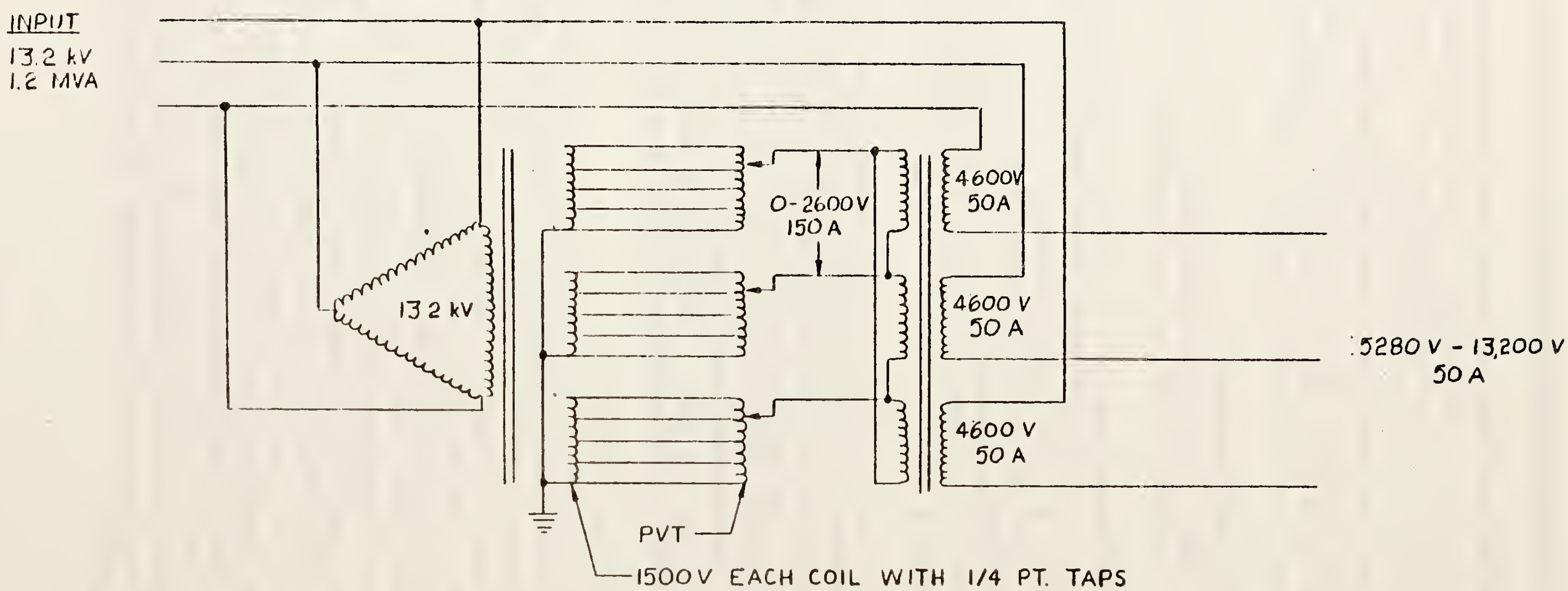


Figure 7 Replacement variable transformer stage for the klystron power supply.

The power splitters, phase shifters, waveguide, and controls have all been installed for the 12 MeV linac and are currently being wired up.

4. 12 MeV Linac

The final two 4 m linac sections for the main RTM were shipped to NBS from Los Alamos in February 86 and installed in the RTM room. Once at NBS, they were vacuum leak tested, and the cooling water system was tested for leakage. The two tanks then were connected to the rf system and water cooling lines were installed. Figure 8 shows the completed installation. Once the klystron power supply is repaired, rf conditioning and power testing of the 12 MeV linac will begin.

D. Beam Diagnostics

During FY 1986, construction of beam diagnostics equipment for the RTM beyond the injector line was initiated. The final two rf phase, current and position monitors were constructed and shipped to NBS, where they await installation at each end of the RTM linac. All parts for the construction of 20 viewscreen mechanisms and 20 wirescanners were purchased, and construction of subassemblies and electronics has been initiated.

Wirescanners were tested using the 5 MeV beam from the RTM injector linac. Ground loops produced 20 - 100 mV of noise on the signals observed in the control room, which is a 150 m wire run from the RTM room. This noise was reduced to less than 2mV (or less than 50 µm in position resolution of the beam) by "floating" the oscilloscope used in these tests by means of a ground isolator/monitor. This technique was also found to be necessary for the rf beam monitor signals. Ultimately, the wirescanner signals will be digitized in the electrical service cubicle adjacent to the RTM room, where ground loop noise is not a problem.

The wirescanners were also used this year by an atomic physics group at NBS to detect a 200 nA 2 keV Xe^+ beam. Also, blueprints of the wirescanner were sent to CEBAF at their request for consideration for use with the new 4-6 GeV electron accelerator.

E. Control System

1. Introduction

As stated in last year's report, most of the basic control system (shown in Figure 9) has been installed and operationally tested. The only remaining major subsystem not completed is the wire-scanner diagnostic system. Present plans call for the construction of this system in FY 87.

During the past year work on the control system has been directed toward the design and installation of various device interfaces to the

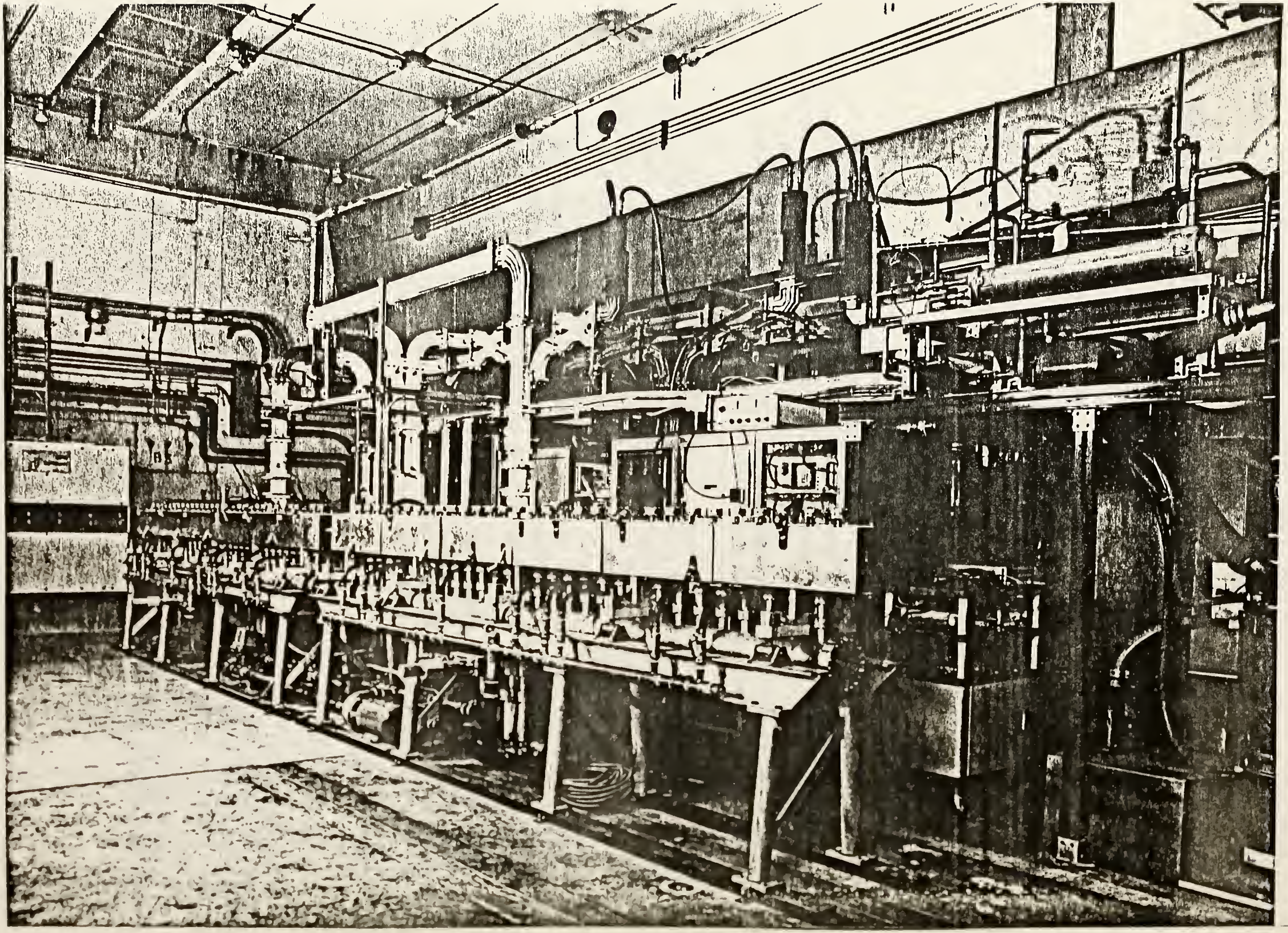


Figure 8 Photograph of the 12 MeV linac installed in the RTM room, with the rf distribution system in the background.

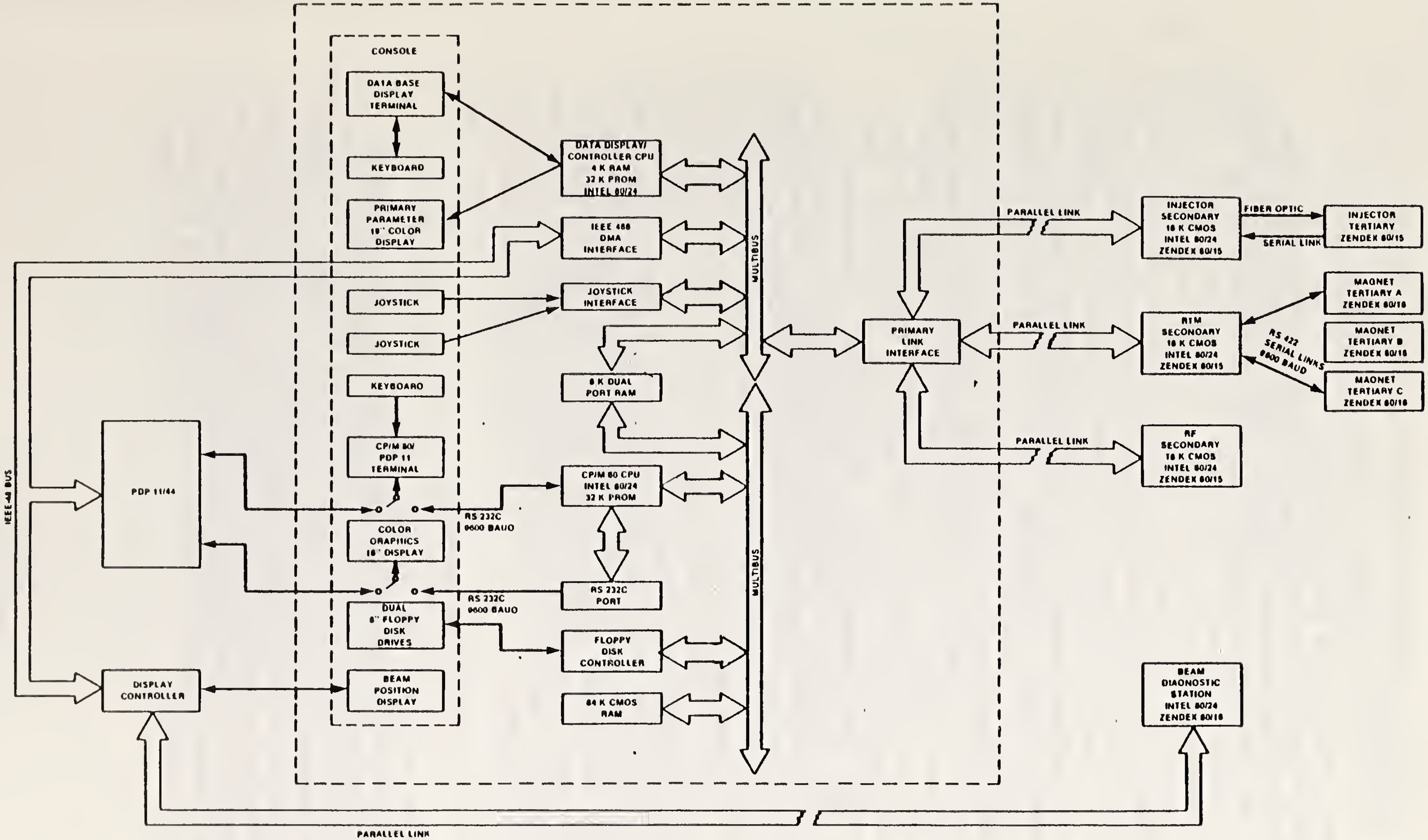


Figure 9 Control System Configuration.

existing secondary stations in preparation for one- and two-pass beam tests, diagnosis and correction of system problems uncovered during our initial 5 MeV beam tests, and development of high level application code for the primary station CP/M subsystem.

2. Analog Signal Switching

A large number of analog signals must be routed to the primary station from the accelerator, including viewscreen television and current monitoring signals, aperture currents, and rf beam monitor signals. While the number of analog signals exceeds 68, no more than 14 signals can be viewed at the primary station at one time.

A custom coaxial matrix switch assembly was designed and assembled, from commercially available modules, to route up to 14 of these analog signals, under operator control, for display at the primary station console. This assembly was installed in the rf secondary station and interfaced to it. Input/output driver code was written to allow operator selection of the analog signal combinations to be routed to the primary station console. This system was used successfully for our initial 5 MeV beam tests and will be expanded to accommodate full accelerator operation.

3. Active Field Clamp Power Supply

Final acceptance testing of the dual-channel, 300 A power supply for the end magnet active field clamps included installation and operational testing of the IEEE-488 bus control input. This required modification of the vendor- supplied controller configuration code and connection to our existing end magnet power supply control and monitoring system. Functional testing of the 488 bus control of the dual channel supply was successfully completed in late 1985.

4. Motor Drives for End Magnet Movement

For two-pass beam tests, it will be necessary to move end magnet E1 parallel to the linac axis for phasing the one-pass, 17 MeV beam with the main accelerator for the second pass. We have selected and tested a stepping motor and a commercial electronic motor drive module which together move the end magnet rapidly and with a setting accuracy of 50 μm. A single IEEE-488 bus connected to the injector secondary station will handle the control and monitoring of the end magnet position, current, and magnetic field. This system will be complete with the delivery of a position monitor and the development of the IEEE-488 bus input/output driver software for the secondary station.

5. Vacuum Control and Interlock Systems

The design of the RTM vacuum control and interlock systems was reported in last year's annual report. At that time, the injector portion of the two systems had been installed, wired, and used for the 5 MeV beam tests. After completion of the initial 5 MeV beam tests, device input/output panels were installed to facilitate the connection of RTM devices to the interlock and vacuum control system. The injector portion of these systems was rewired to the I/O panels and the overall wiring of the system dressed.

In parallel with rewiring of the injector section, the design, wire list preparation and wiring for both one- and two-pass operation and complete accelerator operation is now in progress. No problems are anticipated in having these systems operational and tested in time for the scheduled one- and two-pass beam tests.

6. RF Power Control and Conditioning Program

In addition to the Fortran coded functions described in last years report, we have now developed a moderately complex Fortran coded application program to ramp up the rf power to operating levels in two linac sections at more than two to three times the rate the same operation could be performed by the operator. Similar gains were observed for rf power conditioning of the structures. Since this function requires the nearly simultaneous control of three parameters, namely, rf power, power split between the two structures, and frequency, and the monitoring of many more, it was an obvious operating function for programmed control. This rf control program will be expanded to include the control and monitoring functions for the two sections of the 12 MeV linac once they are placed in operation. With the increased number of control and monitored parameters required by the addition of the 12 MeV linac, this program will be essential for RTM rf system power conditioning and ramping up to operating rf power levels.

7. Improved Control from the Primary Station

During initial rf power conditioning and 5 MeV beam tests, erratic control system operation from the primary station was discovered when attempting to control devices at the end of the data base list in the rf secondary station. Subsequent tests showed this behavior was related solely to control of devices beyond approximately 120 entries in the data base, and was even more evident when attempting to read or write to devices from the primary station CP/M subsystem with high level language application programs, such as the previously discussed rf power control program.

The problem was determined to be caused by insufficient delay in the wait loops of the primary station-to-secondary station link servicing routines in the primary station. Reliable operation was achieved by increasing the delays of both the primary station main code data link read/write requests and the corresponding CP/M link input/output requests from 5 ms to 30 ms. Although this modification to the primary station software does decrease the response time of the control system at the primary station, the required change is small enough that it is not perceptible to the operator.

The overall source of this problem is the linear search algorithm used by the secondary station link service request code. Namely, primary station control/data update request service response times from the secondary stations are a linear function of the specified data position in the database list. Thus, as the data base size of an individual secondary station increases, the worst case (last item in the listing) service request time increases proportionately.

8. Small Magnet Power Supplies

We have developed a design for a 1 A, 15 VDC, bipolar, dual-channel power supply for the many small steering and focusing magnets on the RTM. Two hundred-eight of these supplies were fabricated by a commercial vendor and were tested at Los Alamos for correct operation with the RTM control system. In the past year these power supplies were operated with magnets on the 5 MeV beam transport line, and intolerable current oscillations were observed. After investigating alternate designs to overcome these oscillations, we decided that the most practical solution was the simple addition of a shunt capacitor of approximately 1 μF. This solution limits the output current fluctuations to less than a part in 10^3.

F. Accelerator Theory

1. Introduction

Computer modeling of the RTM is done on the NBS central computing facility to determine design and operating parameters of the RTM and to study the performance characteristics of the machine. At present, accelerator physics codes PTRACE, STRACE, TRANSPORT and TRIM are running on the new NBS central computers, with BEAMRAD expected to be running by the end of FY 1986. Two major improvements were made in STRACE: first, the correct first-order (transverse) motion for a standing-wave (SW) linac has been incorporated; second, the accuracy of the longitudinal motion calculations in linac sections has been improved. A spacing between end magnet E1 and the RTM linac was found which results in a longitudinal phase space match between the injector and the RTM.

2. Conversion to New Computer System

In 1985 NBS replaced its UNIVAC 1100 computer system with a CYBER 205 supercomputer serviced by a CYBER 855 front-end computer. This required that we learn two new operating systems and convert our programs to run on the new system. Our old versions of PTRACE, STRACE and TRIM were converted to run on the CYBER 855 and/or the CYBER 205, but a new version of TRANSPORT that runs on the CYBER 855 was obtained from Fermilab. BEAMRAD should be running on the new system by the end of FY86. We have seen a significant improvement in both speed and accuracy on the CYBER 205. For example, on a particular problem that was run on the UNIVAC 1100 and on the CYBER 205, STRACE used about one tenth the cpu time on the 205 than it did on the 1100. We also ran a large magnet-design problem, using TRIM, on the 205 that had been previously run on the 1100 and compared the output from both runs. The slightly jagged, non- physical magnetic field distribution calculated on the 1100 became smooth on the 205, indicating a reduction in computational error.

3. Improvements in Program STRACE

Two major improvements were made in STRACE: the correct first-order transverse motion in a SW linac has been incorporated, and the accuracy of longitudinal motion calculations in linac sections has been improved.

The transverse particle motion in the old version of STRACE was that of a traveling wave (TW) linac, which is a poor representation of a SW linac. As demonstrated in last year's annual report to DoE (Appendix K), STRACE underestimated transverse focusing in a SW linac by two orders of magnitude. A new subroutine called SWACC, which stands for Standing Wave Accelerator, was written this year to replace the old TW linac subroutine FEACC. SWACC calculates the transverse particle motion in a SW rf linac correctly to first order using a modified version of the first order transverse transfer matrix derived by E.E. Chambers.[4] (We chose to use particle momentum rather than energy as a variable.) A comparison between PARMELA and the improved version of STRACE showed an agreement within 11%.

STRACE calculations of acceleration from 4.7 to 10.5 MeV in a four meter linac section produce errors of about 15 keV in energy and .8 degrees in phase if the section is treated as a single element in the calculation. By subdividing a four meter linac section into smaller mathematical units, errors were reduced to acceptable levels. These errors are greatest at low energies in long linac sections where the assumption of

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[4] R.E. Rand, "Recirculating Electron Accelerators," Accelerators and Storage Rings Vol. 3, Harwood Academic Publishers, 1984.

linear phase shift of the beam particles with respect to the rf wave is invalid. The new accelerator subroutine SWACC automatically breaks up the longitudinal integration into steps such that the phase shift in the first step is less than the specified maximum, DPHMX (a new input parameter). The default value of DPHMX is 2 degrees, which has proved to be adequate for most calculations.

4. Longitudinal Phase Space Matching of Injector Output to RTM Input

A spacing between the RTM linac exit and the effective field boundary of end magnet E1 was found which resulted in a match between the injector and the RTM. Optimization of the longitudinal beam dynamics in the RTM resulted in a fixed 10π keV•deg longitudinal phase space ellipse at 23 MeV, midway between the two 4 m linac sections. Several particles on this ellipse were raytraced backwards, through the 17 MeV turnaround, to the linac entrance. The resulting figure in longitudinal phase space at 5 MeV encloses a region into which the injected beam must fit for proper matching to the RTM. The range of shapes and orientations of this figure was investigated by varying the spacing between the linac exit and end magnet E1. An optimal spacing was found for a good match between the injector and RTM, as shown in Figure 10. Injector linac output phase space, constructed from PARMELA calculations for nominal preaccelerator phase, was sheared by 0.08 deg/keV to obtain a match. The required shear will be accomplished in the 5 MeV transport line by adjusting the field in Q5.

Free Electron Laser Facility (S. Penner)

A study was initiated in FY 1986 to investigate the suitability of the NBS RTM as the electron beam source for a free electron laser (FEL). The study was funded by the Office of Naval Research, and performed in collaboration with Drs. Phillip Sprangle and Cha-mei Tang of the Naval Research Laboratory (NRL).

An FEL extracts energy from an electron beam in the form of a coherent beam of nearly monochromatic radiation. The principle of operation is as follows: A relativistic electron beam is passed through a "wiggler," wherein an array of magnets produces a periodic strong transverse magnetic field. The electron beam emits synchrotron radiation in a narrow cone centered on its direction of propagation through the wiggler due to the transverse oscillations of the electrons in the magnetic field. Synchrotron radiation from successive periods of the wiggler will be coherent when the wavelength, λ, of the radiation satisfies the relationship

$$\lambda = \frac{\lambda_w}{2\gamma^2} (1 + K^2),$$

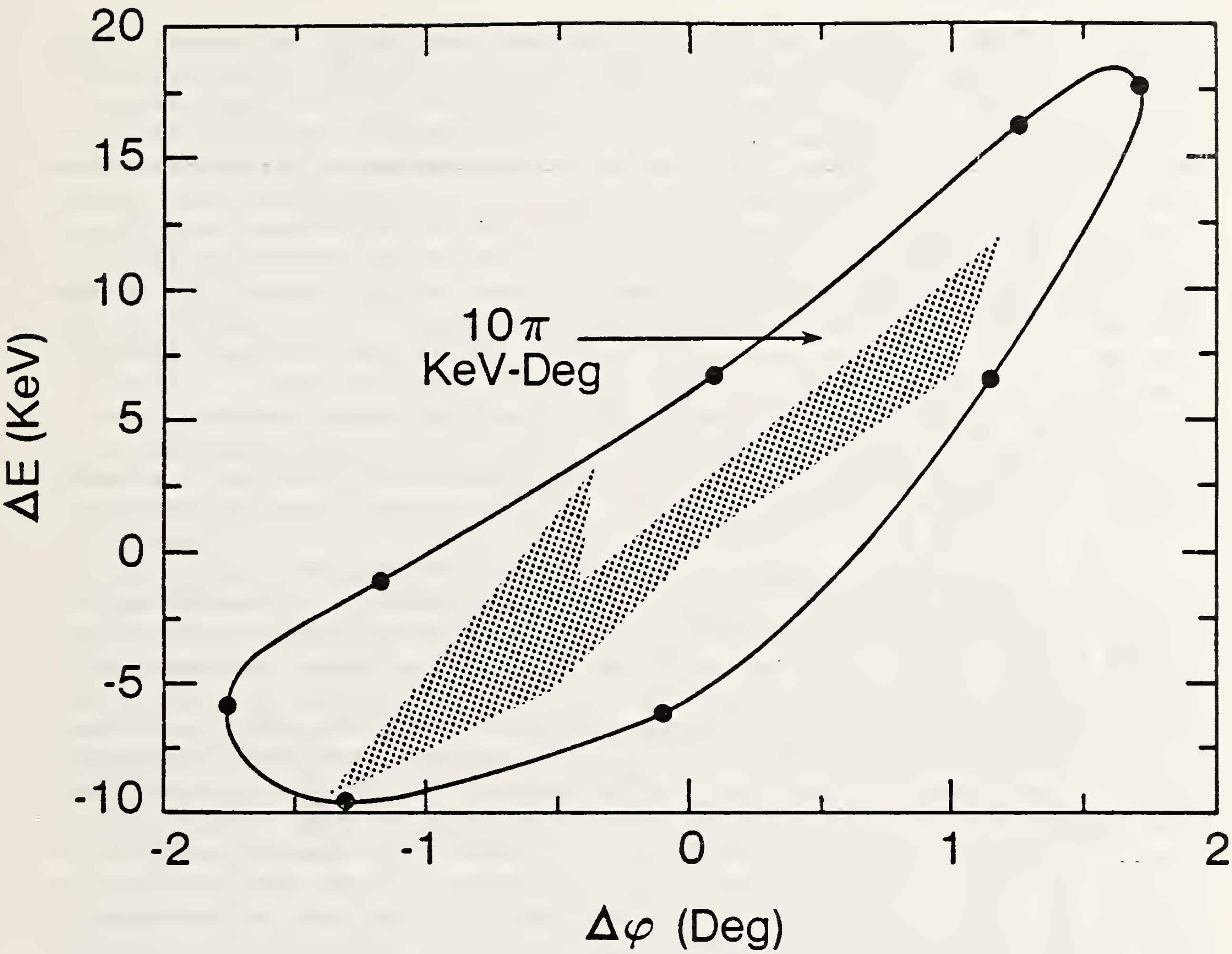

Figure 10 Longitudinal phase space plots of the beam at the entrance to the linac for the best match between injector and RTM. The shaded region represents the injector beam particles (from PARMELA), for nominal preaccelerator phase, after undergoing a .08 deg/keV shear in the 5 MeV transport line. It is contained within the RTM longitudinal acceptance for 10 keV-deg.

where λ_w is the wiggler period, γ is the electron energy in units of electron rest energy, and K is the "wiggler parameter" which is proportional to the strength of the magnetic field and is typically of order unity. The "spontaneous, coherent" radiation is reflected back through the wiggler by a mirror, then reflected again to copropagate with the electron beam. Beam electrons are bunched at the optical wavelength by the electromagnetic fields of the radiation, and thus emit still more radiation. (In a quantum mechanical analysis of the process, additional coherent radiation is stimulated by the presence of the original radiation, hence the use of the term laser in describing the device.) In travelling once through the wiggler, the radiation field is amplified with some "gain," the necessary energy being extracted from the electron beam. If the gain per pass is greater than the sum of all losses per pass, the radiation will build up on successive passes until saturated equilibrium occurs. Losses are due to mirror reflectivity, diffraction effects, and the "outcoupling" of some of the radiation for some, presumably useful, purpose.

The expected small energy spread, emittance, and beam stability of the RTM are very important factors in FEL performance. The operating energy range of the RTM is suitable for producing radiation in the wavelength range of about 0.25 μm to 10 μm spanning the range from the near UV, through the visible and near IR. The emitted light is extremely intense (hundreds of watts, time averaged, for a 100 kW electron beam) and nearly 100% spatially coherent. The light beam has the same time structure as the electron beam, i.e. pulse lengths of a few picoseconds, and its frequency bandwidth should be just the transform limit of the pulse length (<0.1% in the visible region). In addition to the fundamental laser radiation, significant amounts of spontaneous coherent radiation are emitted at the odd harmonics of the fundamental. For some applications, useful amounts of radiation would be available at wavelengths of order 30 nm. The combination of high power, easy tuneability over a very large range, spatial coherence, reasonably small bandwidth and a continuous train of very short pulses makes an FEL an extremely useful tool for a very wide variety of applications including photochemistry, surface science, atomic and molecular physics, and biophysics.

The ONR-funded feasibility study showed that the gain of an FEL based on the design peak current of the RTM would be marginal (i.e. 1-3 percent per pass) even with a very long, precise, and expensive wiggler. The problem is the relatively small peak current of the CW microtron, 140 mA, limited by the available RF power at design beam energy. We examined the possibility of increasing the peak current by recapturing some of the electron energy in the RTM by beam recirculation. This proved not to be useful because of the small longitudinal phase space acceptance of the RTM (compared to the degraded longitudinal emittance of the beam which has generated laser light). We next considered enhancing the peak current without increasing the average current by injecting electrons during only a fraction of the RF cycles, i.e. by not filling every RF "bucket." For example, if we fill only one bucket in 24, the average current is within the power limit for peak current up to 3.4 A. With peak currents in excess of 2 A, the FEL single-pass (small signal) gain is in the range 10-20% with a 3.6 m long wiggler, having a 2.8 cm period for wavelengths in the range 0.25 - 2 μm. For longer wavelengths, a shorter wiggler is used. There are several possible methods for generating the required pulses of electrons for subharmonic injection. The method which appears most attractive is to use a short-pulse mode-locked laser operating at a subharmonic of the RF frequency to produce electrons by photoemission from a suitable cathode material.

In response to an announcement by the Strategic Defense Initiative Office (SDIO) of the possibility of funding for a facility for performing research in biomedical and materials sciences applications of FELs, we have performed a preliminary design and cost study and submitted a proposal to develop an FEL facility at NBS using the RTM. The proposal, developed jointly by NBS and NRL, requests $4.9 million from SDIO over three years. NBS would, in addition, supply a new laboratory building, three staff scientists salaries, RTM operation as needed to test and calibrate the FEL, and some general purpose equipment. The new laboratory, a 2000 ft^2 building located above the existing linac facility, would house the experiments using the FEL radiation. Since it would be shielded from the underground space containing the RTM and FEL, there would be no significant background radiation from the RTM (or linac) in this area. We are proposing that the FEL radiation be used by NBS staff and external collaborators for programs in atomic physics, molecular spectroscopy, biophysics, surface sciences, and FEL technology. Outside users from such institutions as the Uniformed Services University of the Health Sciences (USUHS) and Electro-Optics Branch of the Center for Devices and Radiological Health of FDA have expressed interest and enthusiasm for using the facility for biomedical research applications.

LINAC OPERATIONS (J. Broberg)

Division 535, Radiation Source and Instrumentation Division

The NBS Electron Linac was designed in 1960 with maximum flexibility in order to support a wide variety of program activities of interest to NBS. Due to the changes in program directions the linac has been used mostly for neutron cross section standards and radiography. We also have supplied beam to a group from Pennsylvania State University for calibration of nuclear detectors.

The Linac Operations staff has in spite of its relatively small size, continues to achieve a highly commendable operating efficiency as described below. The staff operates and maintains the facility as well as designs, constructs, and installs new equipment to improve operations and extend the capability of the Linac and the beam handling system. The Mechanical Instrumentation Group within the Division provides help by maintaining the integrity of the vacuum and cooling systems of both the Linac and beam handling system as well as designing, constructing, and installing mechanical components. All but 140 hours of beam time was run for the Neutron group; that was used by Pennsylvania State University. We have supplied 1275.0 hours to actual beam time to the Neutron group at an efficiency approaching 90% (exact efficiency figures are difficult to calculate due to many canceled scheduled times and running nonscheduled runs for the Neutron program). The unscheduled maintenance of 86.0 hours, through August 31, is broken down and summarized by system in Table I. The small amount of unscheduled maintenance is due in part to having extra periods during no operation to do preventive maintenance.

The RTM is operational to an extent that testing is now necessary, and since the building water cooling system will not permit both the Linac and the RTM to operate simultaneously, their operations must be scheduled jointly. The long range plan is to operate the Linac approximately 1/3 of the time and the RTM 2/3 of the time. With our operational staffing and assuming an 80% efficiency of operation this should give us about 1200 hours of Linac beam time and about 2400 hours of RTM time a year.

TABLE I

LINAC OPERATIONS

FY 86

LINAC: Total unscheduled maintenance 86.0 hours

System:

Modulators	34.4 hours	40.0%
Injector	21.5 hours	25.0%
RF Drive	4.3 hours	5.0%
Vacuum	8.6 hours	10.0%

No other system or item over 2%.

BHS: Total unscheduled maintenance 5.0 hours.

Balance of total unscheduled maintenance, 12.2 hours, due to air conditioning and power outage.

INSTRUMENTATION SERVICES

Division 535, Radiation Source and Instrumentation

Electronic Instrumentation Maintenance and Construction (J.K. Whittaker & J. Owen)

Provision of electronics instrumentation maintenance and construction services for the experimental programs of the Center for Radiation Research is a continuing responsibility of the Radiation Instrumentation Group in the Division. Instruments designed and constructed during 1985 number about 85 and maintenance has involved about 67 instruments.

Instrumentation Design and Construction (J.K. Whittaker, N.D. Wilkin, A.B. Marella, & J. Owen)

Design and construction of experiment and system control and interlock instrumentation is a continuing and important element of the Radiation Instrumentation Group activities. Examples of this instrumentation this year include: automatic sample changer redesign and construction (used in the manufacture of SRMs); design, construction and modification of instrumentation for the State Regional Calibration Centers (for x-rays); computer controlled specimen manipulator for an electron microscope; alpha-particle detector system (computer controlled) using RAM cell upset; wire-chamber detector for an electron spectrometer; microcomputer system integration and applications; microcomputer CAD system integration and test; pulse-radiolysis data acquisition instrumentation; miscellaneous computer systems, communication links, interlock systems, detector electronics, and radiation monitors

Instrumentation Support for Physics and Chemistry Projects (J.K. Whittaker, N.D. Wilkin, & A.B. Marella)

Consulting and systems instrumentation has been provided to scientists in programs relating to neutron physics, electron physics, surface electron physics, x-ray dosimetry, radiation chemistry, vacuum ultraviolet physics (SURF), analytical chemistry, and physical chemistry. In addition, very considerable support has been provided for RTM projects, one Group technician being assigned full-time to the project with extra assistance on a requirements basis apart from the systems noted above.

Application of microcomputers for many laboratory and office requirements continues, available financing limiting the number. The new wire chamber detectors for electron physics is nearly complete with all the (micron-sized) wire, having been soldered into place and nearly all physical construction problems solved. The first generation of an alpha- particle detection system has been delivered. This used the individual bit-cells of an unencapsulated dynamic RAM to detect the radiation. Further development of this system will be undertaken. Initial studies have been started for the automation of the NBS standard microcalorimetry system for X-ray dosimetry.

The Group continues to operate the HP 9845-based computer-aided design (CAD) system available to all NBS personnel. A second HP 9836-based system has been brought on-line for Group CAD operations. The intense use of these CAD facilities has enabled the Group to maintain effective productivity in the face of a labor shortage. There also is an opportunity to use computer-aided engineering (CAE) software and hardware to enhance the effectiveness of Group personnel. It is estimated that the total cost of present CAD systems was recovered in no more than 9 months of operation. New CAE systems should be even more cost effective.

The Tektronix software development system has been delivered and is operational. This is a joint operation between Group and RTM personnel. Further expansion of the system to include more advanced emulation facilities (for the 68020 microcomputer) and for a digital analysis system with multichannel digital timing analysis (with software recognition facility) is an excellent opportunity.

Consultation by the Group expert staff continues to be important - not only to CRR but to other Centers in NBS. The cooperative AID program with the Egyptian National Institute of Standards and the Egyptian Organization for Standards and Quality Control has now been successfully completed with Whittaker spending 3 weeks in Cairo with these two organizations in July 1986.

The cooperative program with Harry Diamond Laboratories continues very successfully with seven microcomputer systems and two microcomputer-based CAD systems being delivered. The consultation component of this program has been most productive.

Mechanical Instrumentation Services (D. Mohr)

Mechanical instrumentation services were provided for the Center for Radiation Research in connection with its particle accelerators and its experimental programs. The services provided consisted of design and construction of new equipment and facilities as well as maintenance and modification of existing equipment to improve performance and reliability.

Instrumentation Design and Construction (D. Mohr)

Design and construction of mechanical devices is an ongoing and important element of the mechanical instrumentation group activities. Examples of these devices built this year are: 15° and 30° high precision dipole magnets for the RTM 5 MeV injection beam line; four dipole magnets for the RTM main accelerator axis; numerically controlled linear motion assembly for the 30 ton RTM end magnets; precision optical alignment fixtures for the RTM end magents and the 12 MeV RTM main accelerator.

Installation and Maintenance of Facilities (D. Mohr)

Another major element of our activities is installation and maintenance of major facilities. Examples this year are: installation and alignment to ±.002" of the RTM 12 MeV main accelerator; installation of the RF drive system to the RTM main accelerator including both power splitters and phase shifters; rebuilt a Model 12 electron gun for the NBS linac; rebuilt vacuum pumps for SURF, Linac and the 3 MeV Van de Graaff; maintained the mechanical and vacuum equipment on the linac to allow in excess of 90% beam efficiency.

The group staff continues to provide consultation service to other groups in CRR and other NBS organizations. The staff is also consulted by people outside NBS who build and operate accelerators worldwide.

The single CAD/CAM workstation is operational and has allowed us to design six precision magnets this year. Lack of funds prevented the installation of a second needed unit this year. The full potential of this technology will only be realized when several more units are operational.

RADIATION INSTRUMENTATION STANDARDS (L. Costrell)

Division 535, Radiation Source and Instrumentation

The Division provides national leadership in the standardization of nuclear instrumentation. The standards work falls into three categories as follows: (a) National Voluntary Standards - The Division plays an active role in the development and processing of Standards of the Institute of Electrical and Electronic Engineers (IEEE) and the American National Standards Institute (ANSI) and participates in the associated policy boards. L. Costrell serves as Chairman of ANSI Committee N42 on Radiation Instruments and as Secretary of the IEEE Nuclear Instruments and Detectors Committee. In these capacities he has processed a considerable number of ANSI and IEEE standards, serves on the ANSI Nuclear Standards Board, and is a member of its Planning Committee.

(b) NIM Committee Standards - This involves development and maintenance of instrument standards, in cooperation with the National Laboratories, primarily for use in nuclear applications. NBS has the management responsibility for this work, with L. Costrell serving as Chairman of the NIM Committee. The Nuclear Instrumentation Module (NIM) system has been adopted nearly universally in the U.S. and is a continuous coordination requirement involving contact with numerous laboratories and manufacturers. Similar management, direction and maintenance are provided in the U.S. with regard to the international CAMAC (Computer Automated Measurement and Control) system that is utilized in the National Laboratories and in a large number of other laboratories and installations throughout the world. A third system for which the Division has similar responsibility is the FASTBUS high speed modular data acquisition system for high energy physics and other applications. The FASTBUS development has been a major effort with commercial equipment now available and systems in operation or in preparation in numerous laboratories in the U.S., Europe, and Japan.

The preparation of reports for the above systems involves a number of individuals and laboratories. Coordination and processing, as well as writing of some sections, is handled by the National Bureau of Standards. The documents are usually issued as Reports of the Department of Energy and then processed as Standards of the Institute of Electrical and Electronics Engineers (IEEE), the American National Standards Institute (ANSI), and the International Electrotechnical Commission (IEC).

The Nuclear Instrument Module (NIM) system[1,2] has had a phenomenal acceptance in laboratories and industry throughout the world. There is a continuous coordination requirement involving contact with numerous laboratories and manufacturers and the resolution of questions that arise. In order to allow and encourage exploitation of technological development without impairing compatibility and interchangeability, continued vigilance and direction is essential and is provided. The shift from discrete components to integrated circuits and the increasing use of computers and microprocessors necessitates continued accommodation to those devices. Work is proceeding on updating the NIM standard in the light of developments and practice. Also, the division continues to provide information regarding the CAMAC standards.[3]

The FASTBUS standard, previously issued as a Department of Energy Report,[4] has been updated and issued as a standard of the Institute of Electrical and Electronics Engineers (IEEE) and the American National Standards Institute (ANSI).[5] Processing as an international standard of the IEC is also progressing with the draft currently being balloted by the National Committees.

The NIM and CAMAC standard instrumentation projects have resulted in a savings of at least 1.9 billion 1982 dollars according to a study conducted for the Department of Energy by a firm of economics consultants.[6] The study report states that the 1.9 billion dollars is considered to be a minimum figure conservatively arrived at on the basis of available data. 1.7 billion dollars is attributed to the NIM system initiated by the

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1 "Standard Nuclear Instrument Modules," AEC (now DOE) Report TID-20893 (Rev 4), July 1974 (currently under revision).

2 "Standard NIM Digital Bus (NIM/GPIB)," Department of Energy Report DOE/ER-0173, August 1983.

3 CAMAC Instrumentation and Interface Standards, IEEE Publication SH08482, Library of Congress Catalog No. 8185060 (ANSI/IEEE Stds 583, 595, 596, 675, 683, 726, 758).

4 "FASTBUS Modular High Speed Data Acquisition and Control System," DOE Report DOE/ER-0189, December 1983.

5 "FASTBUS Modular High Speed Data Acquisition and Control System," ANSI/IEEE Std 960-1986.

6 "Benefit Analysis of Selected Accomplishments of DOE's Office of Health and Environmental Research," Final Report RR-166, November 29, 1982, Ecosometrics, Inc. (M. Lago, M.J. Ramsdell, S.F. Knapp, S.I. Siddique, Bethesda, MD.)

Center for Radiation Research[7] and the balance of 200 million dollars to the CAMAC instrumentation system developed by the ESONE Committee of European Laboratories with the active collaboration of the U.S. NIM Committee and the CRR. The report adds: "The benefits were estimated only if they could be documented from the literature or telephone contacts. There are a number of other direct and indirect benefits associated with the use of CAMAC and NIM interfaces which were not considered in this analysis because no measureable data were available." The total worldwide savings can be reasonably projected to be double the U.S savings.

(c) International Electrotechnical Commission - L. Costrell serves as Technical Advisor to the U.S. National Committee of the IEC for IEC Committee TC45 on Nuclear Instruments. He serves as Chief U.S. Delegate to TC45, as Chairman of the Working Group on Detectors and as a member of the working groups on Interchangeability and on Terminology. Numerous IEC draft documents were prepared and reviewed resulting in a number that were published and others that are to be published. These include documents that are technically identical to the NIM and CAMAC standards.[1,2,3] Similarly, the FASTBUS document being processed as an international standard is to be technically identical to ANSI/IEEE Std 960-1986[5] and the international standard on test procedures for germanium semiconductor detectors is to be technically identical to ANSI/IEEE Std 325 that is to be published soon.

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[7] "Standard Modules for Nuclear Instrumentation," NBS Report 8137, December 5, 1963, L. Costrell.

INVITED TALKS

Division 535, Radiation Source and Instrumentation

Ayres, R.L., "Control System for the NBS Microtron Accelerator," Second International Workshop on Accelerator Control Systems, Los Alamos, New Mexico, October 7, 1985.

Costrell, L., Short Course, "FASTBUS Modular High-Speed Data Acquisition and Control System", National Science Symposium, San Francisco, California, October 22, 1985.

Costrell, L., "Standard Modular Instrumentation Systems Developed for the Nuclear Field," The Institute for Standardization of China, Beijing, The People's Republic of China, May 13, 1986.

Costrell, L., "Development of the Scintillation and Semiconductor Radiation Detectors", The Institute for Standardization of China, Beijing, The People's Republic of China, May 14, 1986.

Costrell, L., Short Course, "FASTBUS Modular High-Speed Data Acquisition and Control System," Los Alamos National Laboratory, Los Alamos, New Mexico, September 16 - 17, 1986.

Cutler, R.I., and Wilson, M.A., "Report on NATO Advanced Study Institute on High Brightness Accelerator," NBS Nuclear, Radiological and Accelerator Physics Seminar, Gaithersburg, Maryland, September 18, 1986.

Penner, S., "Linacs for Microtrons and Pulse Stretchers," 1986 Linear Accelerator Conference, Stanford, California, June 5, 1986.

PUBLICATIONS

Division 535, Radiation Source and Instrumentation

Department of Energy NIM Committee, L. Costrell, Chairman and Project Leader, ANSI/IEEE Std 960-1986: "FASTBUS Modular High-Speed Data Acquisition and Control System", The Institute of Electrical and Electronics Engineers, Library of Congress No. 85-081331, 1986.

Martin, E.R., Trout, R.E., Wilson, B.L., Ayres, R.L., and Yoder, N.R., Control System for the NBS Microtron Accelerator, Proceedings of the Second International Workshop on Accelerator Control Systems, Los Alamos, New Mexico, October 7-10, 1985.

Penner, S., Linacs for Microtrons and Pulse Stretchers, to be published in the Proceedings of the 1986 Linear Accelerator Conference, Stanford, California, June 2-6, 1986.

Tang, C-M., Sprangle, P., Penner, S., Kincaid, B.M., Freeman, R.R., Proposal for FEL Experiments Driven by the National Bureau of Standards' CW Microtron, Proceedings of the 7th International Free Electron Laser Conference, Tahoe City, California, September 8-13, 1985.

PUBLICATIONS IN PREPARATION

Division 535, Radiation Source and Instrumentation

Cutler, R.I., Owen, J.C., and Whittaker, J.K., Performance of Wire Scanner Beam Profile Monitors to Determine the Emittance and Position of High Power CW Electron Beams of the NBS-Los Alamos Racetrack Microtron (in preparation).

Cutler, R.I., and Young, L.M., Performance of the High Power RF System of the NBS-Los Alamos Racetrack Microtron (in preparation).

Debenham, P.H., Penner, S., Wilson, M.A., and Bruce, S.S., Injection Chicane Magnets for a Racetrack Microtron (in preparation).

Maruyama, X.K., Penner, S., Tang, C., and Sprangle, P., Proposal for a Free Electron Laser Driven by the National Bureau of Standards' CW Microtron (in preparation).

Penner, S., RF Linac Based Free Electron Lasers (in preparation).

Tang, C.M., Sprangle, P., Penner, S. and Maruyama, X.K., Analysis of FEL Performance Utilizing the National Bureau of Standards' (NBS) CW Microtron (in preparation).

Wilkin, N.D., Downing, G., and Whittaker, J.K., Alpha Particle Detector Using RAM Cell Upset (in preparation).

Wilson, M.A., Ayres, R.L., Cutler, R.I., Debenham, P.H., Lindstrom, E.R., Mohr, D.L., Penner, S., Rose, J.E., Young, L.M., and Stovall, J., Performance of the 5 MeV Injector for the NBS-Los Alamos Racetrack Microtron (in preparation).

Wilson, M.A., Debenham, P.H., Penner, S., and Bruce, S.S., Orbit Reversing Magnets for the NBS-Los Alamos Racetrack Microtron (in preparation).

TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION AND LEADERSHIP

Division 535, Radiation Source and Instrumentation

Robert L. Ayres

Member, ANSI Technical Committee N42.2 on Procedural Standards for Calibration of Detectors for Radioactive Materials

Member, CRR Word Processing Task Force

Member, IEEE P1014/VMEbus Standard Committee

Member, NBS RIF Assignment Panel

Member, Science and Technical Pool, Science Panel, Committee on Interagency Radiation Research and Policy Coordination (CIRRPC)

Member, NBS Storeroom Committee for ADP

U.S. Representative, Life Sciences Working Group of the International Committee for Radionuclide Metrology

Louis Costrell

Chairman, ANSI Technical Committee N42, Nuclear Instruments

Chairman, DoE National Instrumentation Methods (NIM) Committee

Chairman, NBS Inventions and Patents Committee

Chairman, IEC/TC45 Working Group-9 on Radiation Detectors

Chief U.S. Delegate, International Electrotechnical Commission (IEC), Technical Committee on Nuclear Instruments (IEC/TC45)

Member, ANSI Technical Committee N41, Controls, Instrumentation, and Electrical Systems for Nuclear Power Generating Stations

Member, IEC/TC45 Working Group-1 on Classification and Terminology

Member, IEC/TC45 Working Group-3 on Interchangeability

Member, 1985 Particle Accelerator Conference Organizing Committee

Member, U.S. National Committee of International Electrotechnical Commission (IEC)

Division 535, Technical and Professional Committee Participation and Leadership (cont'd.)

Secretary, Institute of Electrical and Electronics Engineers Nuclear Instruments and Detectors Committee of IEEE Nuclear and Plasma Sciences Society (IEEE/NPSS)

Technical Advisor, U.S. National Committee of IEC

Philip H. Debenham

Member, DoE POISSON Working Group

Member, SDIO review team for the Neutral Beam Test Facility and the Radiation Effects Facility at Brookhaven National Laboratory

Member, Small Business Innovation Research Review Panel

Member, 1987 Particle Accelerator Conference Program Committee

Participant, Workshop on "CEBAF Spectrometer Magnet Design and Technology"

Samuel Penner

Chairman, 1987 Particle Accelerator Conference

Member, Organizing Committee for 1986 Heavy Ion Fusion Symposium

Member, Organizing Committee for 1986 Linear Accelerator Conference

Julian K. Whittaker

Member, ASTM Committee D-22 on Methods of Sampling and Analysis of Atmospheres

Member, DoC Industry and Trade Administration, Electronic Instrumentation Technical Advisory Committee

Division 535, Technical and Professional Committee Participation and Leadership (cont'd.)

Neil D. Wilkin

Member, Editing Committee for IEEE Nuclear and Space Radiation Effects Conference Publication

Member, Electronics Storeroom Committee, NBS

Senior Member, Institute of Electrical and Electronics Engineers

Mark A. Wilson

Member, Organizing Committee for Heavy Ion Fusion Symposium, Washington, DC, May 27-29, 1986

MAJOR CONSULTING AND ADVISORY SERVICES

Division 535, Radiation Source and Instrumentation

1. R. Ayres serves as a member of the U.S. Pharmacopoeia Convention Advisory Panel to the Subcommittee on Radiopharmaceuticals.

2. S. Penner and M. Wilson continue to provide Accelerator Technology and Assessment and Oversight for DARPA.

3. S. Penner serves as a consultant to the U.S. Army Strategic Defense Command on particle accelerator issues related to programs in Free Electron Lasers and Neutral Particle Beam Weapons.

4. S. Penner is on a part time detail for one year to the Department of Defense, acting as Scientific Advisor to the Director, Innovative Science and Technology Office, SDI.

5. J. Whittaker serves as a consultant on instrumentation and instrumentation maintenance and repair to AID for the Egyptian Government Standards Laboratories.

6. J. Whittaker serves as a consultant on electronics instrumentation and instrumentation repair and maintenance to the University of Petroleum and Minerals, Dhahran, Saudi Arabia.

7. N. Wilkin serves as consultant on microcomputers and semiconductor radiation hardness testing to Harry Diamond Laboratories.

8. N. Wilkin serves as consultant on microcomputer control of fuze instrumentation for Harry Diamond Laboratories.

SPONSORED SEMINARS AND COLLOQUIA

Division 535, Radiation Source and Instrumentation

NBS Nuclear, Radiological & Accelerator Physics Seminar, "Technology Options for CEBAF," Christoph Leemann, Continuous Electron Beam Accelerator Facility, Gaithersburg, Md., November 1, 1985.

NBS Nuclear, Radiological & Accelerator Physics Seminar, "Large Momentum Transfer Electron Scattering and the Compression Modules of Nuclear Matter," Joseph Speth, KFA Julich & University of Bonn, Gaithersburg, Md., July 2, 1986.

TECHNICAL ACTIVITIES

Division 536, Ionizing Radiation

The functions of the Ionizing Radiation Division are summarized in the following table:

- Provides primary national standards, dosimetry methods, measurement services, and basic data for applications of ionizing radiation (x rays, gamma rays, electrons, neutrons, and radioactivity, etc.) in such areas as:

  - Radiation protection of workers and the general public
  - Radiation therapy and diagnosis
  - Nuclear medicine
  - Radiography
  - Industrial radiation processing
  - Nuclear energy
  - National defense
  - Environmental protection

- Conducts theoretical and experimental research on the fundamental physical and chemical interactions of ionizing radiation with matter to provide the competence for:

  - Developing improved understanding of the physical stage of the interaction of ionizing radiation with matter
  - Developing an understanding of basic mechanisms involved in radiation-induced chemical transformations and the parameters that influence the yields of short-lived intermediates, final chemical products, and biological effects
  - Developing improved methods for radiation measurement, dosimetry, and radiography
  - Developing improved primary ionizing radiation standards
  - Producing highly accurate standard reference data for ionizing radiation or radioactive materials

- Provides essential standards and measurement support services to the National Measurement Support System for Ionizing Radiation that provides calibrations and measurement quality assurance services to:

  - Medicine
  - Industry
  - States
  - Other Federal Agencies

- Develops and operates well-characterized sources of electrons, photons, and neutrons to provide:

  - Primary radiation standards and fields
  - Well-characterized beams of radiation for research on radiation interactions and for measurement methods development.

The group structure (with leaders) of the Ionizing Radiation Division is:

Ionizing Radiation Division (R. S. Caswell)
Office of Radiation Measurement (E. H. Eisenhower)
Radiation Theory (M. J. Berger)
Radiation Chemistry & Chemical Dosimetry (M. G. Simic, Acting)
Neutron Measurements & Research (O. A. Wasson)
Neutron Dosimetry (J. A. Grundl)
Radioactivity (D. D. Hoppes)
X-ray Physics (J. W. Motz)
Dosimetry (R. Loevinger).

Some of the thrusts of the Ionizing Radiation Division at this time are: (1) radiation chemistry and chemical dosimetry; (2) planning a facility for high-energy electron and photon dosimetry using the microtron; (3) a new technique for high sensitivity in radioactivity measurement, SIRIS (sputter-induced resonance ionization spectroscopy); (4) documentation of all our existing calibration services; (5) improvement of our national measurement standard for radon and measurement compatability among leading national laboratories; (6) automation of standards facilities and calibration services; and, (7) measurement quality assurance of ionizing radiation measurements throughout the nation using an intermediate-level laboratory network.

Office of Radiation Measurement

The function of the Office of Radiation Measurement is to promote the dissemination to federal, state, and local radiation control programs, and to the medical, industrial, and defense communities, of the measurement standards and technology required for reliable measurement of ionizing radiation. The Office assists the technical organizational components of the Ionizing Radiation Division in monitoring the radiation measurement needs of these national user groups, and in activities undertaken to meet national needs. The latter include methods for improving the consistency of field measurements with the national physical measurement standards, through a national system of secondary standards laboratories. The Office maintains liaison with organizations that conduct measurement-intensive programs in the areas of radiation safety, energy, health, and environmental contamination. Examples are the Nuclear Regulatory Commission, Department of Energy, Food and Drug Administration, Environmental Protection Agency, Health Physics Society, and the Conference of Radiation

Control Program Directors. The Office participates in collaborative programs with these organizations to satisfy specific measurement quality assurance requirements. Another function of the Office is to provide the chairman for American National Standards Committee N43, concerned with equipment for non-medical applications of ionizing radiation.

Survey Instrument Calibration Laboratories (E. H. Eisenhower)

The quality of measurements made for radiation protection is of increasing concern to radiation workers, employers, and regulatory agencies. An instrument used to make these measurements must be calibrated periodically in order to achieve adequate accuracy.

During the meeting of its Executive Board on June 29, 1986 the Health Physics Society approved the implementation of a national program whereby it will accredit laboratories that calibrate ionizing radiation survey instruments. This program is an outgrowth of a workshop held by NBS in July 1984, and was developed in response to demand from the radiation measurement community. The Society plans to accredit laboratories at the secondary and tertiary levels, using technical criteria developed collaboratively with the NBS Office of Radiation Measurement to evaluate their qualifications and performance. It is estimated that as many as 12 secondary laboratories will be accredited, and that up to 40 may be accredited at the tertiary level. NBS will be represented on the team that will do on-site assessments of secondary laboratories and will periodically test their calibration performance. These secondary laboratories will, in turn, assess candidate tertiary laboratories and test their performance. Accredited laboratories at both levels will follow approved, documented procedures for providing calibration services and routine quality control. The program is expected to become operational in January 1987 and will be self-supporting through fees payed by accredited laboratories. Initially, laboratories will be accredited for calibrations with x and gamma radiation; neutron and beta radiation will be added in the future.

Directory of Calibration Laboratories (H. T. Heaton & E. H. Eisenhower)

In cooperation with the Radiation Measurements Committee of the Conference of Radiation Control Program Directors, the Office has revised the 1981 "Directory of Commercial Calibration Services for Ionizing Radiation Survey Instruments". The revised directory contains information provided by 95 laboratories in response to a questionnaire. This information is presented in three tables. The first lists each company by name, state, number and types of radiation sources available for calibrations (alpha, beta, gamma, x, and neutron), whether repair services are offered, and pertinent limitations on services. The second table provides detailed information about the calibration services provided by each company, including type of radiation source, range of intensities and energies available, method used, and claimed calibration accuracy. The third table shows the name of each company contact, plus address and telephone number. Introductory material includes definitions of terms (calibration, accuracy, survey instrument, transfer standard), the fundamentals of measurement quality assurance (MQA), and characteristics of radiation sources. The 1981 version of this directory was prepared in response to numerous requests about the availability of calibration services, and has proved to be very useful. It is now outdated and will be replaced by the new, improved version.

State-Operated Calibration Laboratories (H. T. Heaton & E. H. Eisenhower)

The Office is continuing its interaction with five states (IL,SC,WA,CA,AR) to establish laboratories for calibrating ionizing radiation instruments used in state and local radiation control programs. Their capability includes x-ray and gamma-ray calibrations at levels suitable for radiation protection and diagnostic applications. When any of these laboratories meets documented criteria, it will be accredited by the Conference of Radiation Control Program Directors (CRCPD).

The first laboratory that achieved accreditation, in June 1984, is located in Springfield, IL. To date it is the only laboratory accredited for both x-ray and gamma-ray calibrations. The radiation sources include 3 Ci and 30 mCi ^{137}Cs calibrators, and a 150 kV x-ray machine. During the past year this laboratory calibrated instruments for eight state radiation control programs. All of these states requested gamma-ray calibrations and two of them requested x-ray calibrations. This laboratory recently purchased a computer and is developing familiarity with its use.

The laboratory in Seattle, WA was the second to be accredited by the CRCPD, in September 1986, but this accreditation is only for gamma-ray calibrations with 3 Ci and 30 mCi ^{137}Cs sources. Permanent installation of the 150 kV x-ray machine is proceeding slowly due to limited funding from the Washington radiation control program. This laboratory has been calibrating instruments for both the Washington and Oregon control programs.

The Columbia, SC laboratory has successfully completed the first performance test for calibrations using a 150 kV x-ray machine. A draft procedures manual has been prepared and an application for accreditation has been submitted to the CRCPD. Once accreditation for x-ray calibrations has been received, installation of the 3 Ci and 30 mCi ^{137}Cs sources will begin.

During the past year the laboratory in Sacramento, CA was remodeled for better space utilization and environmental control. The old manually operated 50 Ci ^{137}Cs source was replaced with a new pneumatically operated unit consisting of three ^{137}Cs sources of 100 Ci, 3 Ci, and 130 mCi. There is also a system with four remotely insertable attenuators to provide 16 combinations for attenuation values between 2 and 8000. A computer was installed during the past year, and a computer program for x-ray and gamma-ray calibrations is being tested for suitability. Specific laboratory parameters necessary to use the computer code are being measured, and a procedures manual is being prepared. Collaboration with personnel from the California Division of Measurement Standards continues to provide procedures for basic supportive measurements.

In Fayetteville, AR two sites are being developed as calibration laboratories. High-level neutron and gamma-ray calibrations will be done at a former experimental reactor facility (SEFOR), and low-level gamma, beta, neutron and x-ray calibrations are planned at the Engineering Experiment Station. Both bare and heavy-water moderated ^{252}Cf neutron sources are available at the SEFOR site, where room return has been determined for various instruments. At the Experiment Station, room return for the bare californium source was recently measured to be between 5 and 9 percent for the instruments of interest. Calibration cross checks for the bare source show agreement to about 1 percent. Monte Carlo calculations for two source encapsulations have been carried out. These calculations show a significant anisotropy in the equatorial plane. A performance test for neutron calibrations is planned for next fiscal year.

Each state-operated laboratory except Arkansas has had its electrometer and picoampere source modified so they can be calibrated using a computer code. All these electrometers and picoampere sources have been recalibrated to provide baseline data for the routine quality control programs used to monitor such system components.

Computer Codes for Instrument Calibration (H. T. Heaton)

Two computer codes have been written primarily to assist the state-operated laboratories in calibrating various pieces of equipment. The first code was written so that each laboratory can calibrate its electrometer and picoamper source in-house. This procedure required modifications to this equipment to provide the additional signals necessary. The zener voltage for the digital voltmeter used to read the feedback circuit in the electrometer is provided as a voltage standard. The output resistors of the picoampere source are calibrated against a known 0.01 percent resistor using an iterative procedure. The calibrated picoampere source is then used to calibrate the coulomb and current ranges of the electrometer. The computer code provides information on how the various components should be set to perform this calibration and analyses the data to determine the appropriate factors.

The second computer code was developed for calibrating instruments in x-ray and gamma-ray fields. The code consists of three major parts. The first part provides procedures and analysis for the routine QC measurements necessary to ensure that all of the equipment used in the calibration procedure is operating within statistical control since the time it was calibrated. The current version of the code has QC procedures for monitoring the electrometer/picoampere source, x-ray machine output for given conditions, gamma source output, in-house test instrument calibration, and environmental parameters in the laboratory. The second part of the code determines the measured field from the x-ray machine and the calculated field at a given distance on a given day from the gamma source. This calculation is based on a non-linear regression analysis to experimental measurements using a model which includes build-up in air, attenuation in air, inverse square dependence, and an approximate term to account for wall return. The last part of the code provides information on calibrating specific types of instruments for x rays and gamma rays and calculates the calibration/correction factor from the measured data. The code warns the operator if the statistical spread in a given set of measurements is greater than expected, if the measured field from a selected x-ray beam at the expected current is not within preselected limits, and if the correction factors for the RADCAL 1015 X-ray Monitor (the instrument most commonly used by state radiation control programs for their compliance measurements) for selected x-ray beams is not within normal variation from the historical data set.

Measurement Theory (R. Collé)

The Office's expertise in the treatment and reporting of measurement uncertainties continues to be very useful to groups both within and external to NBS. In the past year, many individuals and groups have been assisted by the Office. In particular, an Office staff member critically evaluated the uncertainty statements provided in the calibration reports of several Divisions, gave presentations to two groups within NBS, and served on a "panel of experts" at the 1986 International Conference on Precision Electromagnetic Measurements.

A staff member of the Office has also been selected to chair a newly established Working Group on the Expression of Measurement Uncertainties under the aegis of the International Standards Organization. This group has been charged with developing a document, based upon the CIPM recommendations, which will provide guidance on the expression of measurement uncertainties for use within standardization, calibration, laboratory accreditation, and metrology services.

Radon (R. Collé & J. M. R. Hutchinson)

The continuing concern about exposure of the public to radon and radon progeny throughout the United States has resulted in increased interest in the quality of radon measurements. In response to this concern, the Office has continued its activities toward developing new transfer standards and to maintaining liaison interactions with other radon measurement laboratories.

For the development of new transfer standards, the Office continues to collaborate and conduct laboratory studies with staff members of the Radioactivity Group. These collaborative projects included the continuing work on developing a radon flux density standard; the design of an upgraded and expanded primary measurement system which will serve as the replacement for the national standard for radon measurements; and preliminary studies for an independent verification of the primary measurement system calibration.

The Office provides oversight for the overall project to develop a flux density standard. This project was initially funded in part by an interagency agreement with the Environmental Protection Agency. The 40-cm diameter prototype is now fully operational. Following completion of the gas-phase studies described in last year's report, the source was loaded with a radium solution in June. This was preceded by a determination of a complete set of diffusion model parameters for the prototype; modifications for new polyethylene-stainless steel seals in the prototype; fabrication and testing of a new small-volume accumulation chamber which seals to the top of the prototype; and development of loading procedures and a final calibration protocol for the prototype. The first preliminary calibration for the constrained flux density was recently completed. Many additional calibrations and performance evaluations will have to be performed, of course, before the efficacy of the standard is demonstrated. Each test on the standard requires nearly a month-long measurement period because of the long time required to reestablish a steady-state after a change in the boundary conditions of the source. In addition, further work on verifying the diffusion model for the prototype will have to be performed. This verification is necessary since a mathematical model must be used to relate the constrained to unconstrained flux density.

The NBS primary radon measurement system consists of four pulse ionization chambers and ancillary gas-handling and -purification equipment, and serves as the national standard for radon measurements. This system is not only the underpin to the entire NBS radon program, but is also essential for maintaining the quality of radon measurements made throughout the U.S. The existing system has been maintained, for over 40 years, to accurately measure radon against both national and international radium standards. Unfortunately this ancient system is rapidly becoming inoperable. Parts of the instrumentation are original (dating back to the early 1940's) and are now obsolete. Only two of the extant chambers are operable, and both of these have leaks that are increasing in seriousness. The gas-handling manifold has over the years undergone many repairs and modifications, and at present is merely patched together. The chamber backgrounds are nearly intolerable because of the 40-year accumulation of deposited ^{210}Pb (a radioactive progeny in the ^{222}Rn decay chain), and as a result, it is now impossible to perform measurements at typical concentration levels. Because of the importance of this national standard and its existing state, the Office initiated, in collaboration with the Radioactivity Group, plans for its replacement.

The design of an upgraded, modernized and expanded system has been completed, and funding is being sought. This work would include refurbishing the four existing chambers, fabrication of four new chambers and two ZnS(Ag) scintillation cells, and construction of a new dual manifold for gas purification and transfers.

Some preliminary studies to perform an independent verification of the primary measurement system calibration by gamma-ray spectrometry have recently been undertaken. This independent verification is being performed because of a major calibration discrepancy among several leading radon laboratories including NBS. In the past year, the Environmental Protection Agency established a voluntary Measurement Proficiency Evaluation and Quality Assurance Program for commercial radon measurement vendors. This program which is being administered by EPA relies upon the calibration services of several national laboratories which should be related to the national standard maintained by NBS. Unfortunately, a recent intercomparison of radon measurements by these laboratories has revealed a serious discrepancy in calibrations. EPA has also tentatively accepted the calibrations of one of these discrepant laboratories for its radon MQA program. This situation can have highly visible implications. For example, as part of the MQA program, EPA is generating a list of "acceptable" radon measurement laboratories that perform assays for homeowners and other private individuals likely to be affected by the presence of environmental radon. These laboratories will not be on the "accepted" list if their calibrations differ from the presently accepted calibration -- even if they agree with NBS! Given the public sensitivity to the problem of radon, it is crucial to have a generally accepted calibration. It was felt that a demonstration and verification of the pulse ionization chamber calibrations by an independent measurement method would help resolve the existing problem. Studies demonstrating the feasibility of performing these independent measurements by gamma-ray spectrometry have been completed. Funding, both internal and external to NBS, is presently being sought to complete this work which would resolve the extant calibration discrepancies.

In addition to these laboratory studies, the Office continues to coordinate the interactions and measurement intercomparison activities between NBS and other radon measurement laboratories, such as the DoE Environmental Measurements Laboratory, the DoE Technical Measurements Center (operated by Bendix in Grand Junction, Colorado), two EPA laboratories at Montgomery and Las Vegas, the U.S. Bureau of Mines Denver Research Center, and national laboratories including Lawrence Berkeley Laboratory, Argonne National Laboratory, Oak Ridge National Laboratory, and Mound Laboratory.

The Office also continues to advise and collaborate with personnel in state radiation control programs and in other laboratories on radon measurement and calibration procedures. In the past year, this included advising EPA in drafting interim radon measurement protocols, and serving on an informal advisory task force that assisted in establishing EPA's radon MQA program.

Personnel Dosimetry (E. H. Eisenhower)

The national quality assurance program for personnel dosimetry, which is administered by the NBS National Voluntary Laboratory Accreditation Program (NVLAP), has now completed three years of routine operation. At this time, 42 dosimetry processors have been accredited and several more have submitted applications. The Nuclear Regulatory Commission continues its preparation of a final rule that would require its licensees to use only accredited processors. Several states have already included such a requirement in their rules, and more of them intend to do the same.

Technical support and guidance for this program continue to be provided by the Office and the Dosimetry Group. In January 1986 the proficiency testing laboratory became Battelle Pacific Northwest Laboratories (PNL), which replaced the University of Michigan whose contract expired in February. This required the Office to coordinate and conduct an on-site evaluation of the PNL facility and its procedures, and to prepare an extensive report of that evaluation. The Office continues to provide the chairman of an interagency committee that guides and coordinates this national program. An NBS internal report that summarizes the program and the first two years of testing was prepared during the past year.

<u>Committee Activities</u> (R. Collé, E. H. Eisenhower, & H. T. Heaton)

The Office serves on two major interagency committees concerned with environmental radon exposure. The first is the Radon Workgroup of the Interagency Committee on Indoor Air Quality (ICIAQ). This group recently updated its report on the status of current federal activities and priorities for radon research in the U.S. It also drafted a report on the development of a national indoor radon assessment plan and the appropriate Federal role in conducting this large-scale project. The second committee is the Science Subpanel on Radon Protection and Health Effects of the Committee on Interagency Radiation Research and Policy Coordination (CIRRPC). The Radon Subpanel was one of the first five working groups formed by the CIRRPC Science Panel. A report by this subpanel was completed this year, and was accepted by CIRRPC. The report highlights five major radon issues in the U.S. and presents recommendations for addressing these issues. As part of this effort, the Office participated in briefing the Acting Science Advisor to the President, the Staff of the White House Office of Science and Technology Policy, and the full CIRRPC membership.

The Office is represented on another CIRRPC Science Subpanel, on the Scientific Basis of Radiation Protection Standards. This group is in the process of reviewing ICRP Report 26, which is a basic report on international recommendations for radiation protection. Four issues have been identified by the group, the first of which is the recommendation that the quality factor for neutrons be increased by a factor of two. The subpanel is planning a workshop on this issue and will prepare its report shortly thereafter.

As an outgrowth of a workshop held at NBS in July 1984, the Office has organized the Joint Planning Committee for Radiation Survey Instruments and Calibration. The purpose of this committee is to plan and guide implementation of a national instrument testing program and the establishment of a system of secondary standards laboratories in the private sector. Membership is balanced among agencies and organizations in the private, state, and federal sectors to achieve a broad perspective. Two subcommittees have been created to address the major areas of concern: instrument testing and secondary laboratories.

Participation in American National Standards Committee N43, Equipment for Non-Medical Radiation Applications, has continued as chairman of the main committee and as members of writing groups. The committee received its accreditation from ANSI, and a vice-chairman was elected. The subcommittee on irradiators completed draft standard Safe Design and Use of Panoramic, Dry Source Storage Gamma Irradiators (Category II). It will be submitted to the N43 committee for ballot in the near future.

A new ASTM writing group chaired by the Office was formed to prepare a standard practice for performance of calibration laboratories for radiation dosimetry in industrial testing and processing. This standard practice will contain the performance criteria to be met by laboratories that provide calibration services for the measurement of high-level doses in radiation processing and electronic device hardness testing. It is hoped that these criteria will be used as the basis of a laboratory accreditation program in this area. A second draft of the standard practice has been prepared.

I. Radiation Theory Group

Neutron Transport and Dosimetry (C. M. Eisenhauer)

Calculations and measurements in the exposure rooms adjoining the TRIGA reactor at the Armed Forces Radiobiology Research Institute (AFRRI) have continued. Kerma rates inferred from measurements with neutron activation detectors and tissue equivalent ionization chambers agree to about 15%.

The MCNP Monte Carlo code obtained from Los Alamos National Laboratory has been made fully operational on the CYBER 855 computer. Monte Carlo calculations have been made for widely-varying problems such as absorbed gamma-ray dose in small quartz parallelepipeds, neutron sources, transport of neutrons in a D_2O sphere, and air scatter effects on calibration of neutron sources. The code is not yet operational on the CYBER 205 computer.

A manuscript has been written on the subject of air-scatter corrections for calibration of four standard neutron sources defined by ISO. It will be submitted for publication in Radiation Protection Dosimetry, an international journal.

A report has been prepared, describing computer codes for calculating reduction factors in buildings for initial gamma ray and neutrons from nuclear weapons.

Ratio of Positron to Electron Bremsstrahlung (S. M. Seltzer & M. J. Berger)

The calculations of bremsstrahlung cross sections have been extended to positrons. The first systematic study has been made of differences between the radiative energy loss of positrons and electrons. It has been found that the positron/electron energy-loss ratio obeys a simple scaling law, being expressible rather accurately as a function only of the quantity T/Z, where T is the incident-particle kinetic energy and Z is the atomic number of the scatterer. This scaling law makes it possible to obtain the energy loss for positrons without further detailed calculation, using extensive existing electron bremsstrahlung data.

Photon Cross Section Calculation on PC (M. J. Berger)

A database and a computer program have been developed with which one can calculate, on a personal computer, accurate x-ray and gamma-ray cross sections for coherent and incoherent scattering, photoabsorption and pair production, in the energy region from 1 keV to 100 GeV. The program can be used to obtain these cross sections for a standard energy grid, or for any desired list of energies, for all elemental substances and for mixtures or compounds of any desired composition. It is a special feature of the program that in the case of compounds and mixtures the output automatically includes cross sections at and immediately below all the energies corresponding to absorption edges for all the atomic constituents. The program, developed in FORTRAN 77 on an IBM XT, has also been found to work on many other compatible XT and AT machines. The hardware requirements are modest; a 256K memory and a 8087 mathematical coprocessor are sufficient. The required input base (in compressed binary form) is stored on one floppy 5 1/4" disk. The running time for a typical cross section table (approx. 100 energies) is only a small fraction of a minute.

Microdosimetric Event-size Distributions in Water (M. J. Berger)

Microdosimetric calculations have been performed to provide the physics input for the study of the effects of ionizing radiation on living matter. Using accurate, new cross sections for proton-impact ionization, calculations have been made of the statistical fluctuations of energy depositions (event sizes) in small targets in a water medium. These calculations were made for spherical targets with various diameters up to 1 micron, for incident protons with energies between 0.5 and 20 MeV. Similar results were also obtained for incident proton spectra that result from irradiations with 14-MeV or 20-MeV neutrons. Previous calculations in the literature have been carried out mainly in the continuous-slowing-down approximation, that is, disregarding the energy-loss straggling of protons. In the present work the straggling was taken into account by the Monte Carlo method. Furthermore, the calculations included the modification of the event-size spectra due to the transport of energy into and out of the target region by secondary electrons (delta rays).

Space-Shielding Calculations (S. M. Seltzer, M. J. Berger, & G. Barnea)

Radiation transport calculations, based on Monte Carlo methods, have been made to study the shielding of spacecraft against electrons and, in particular, secondary bremsstrahlung originating in the shield. This work was undertaken in response to NASA concerns over the radiation hazards to on-board personnel and/or critical electronic components during the longer space missions planned for shuttle and space-station projects. Using a Monte Carlo code that treats three-dimensional structures, quantitative results have been obtained for radiation environments expected in typical shuttle and geosynchronous orbits. These results indicate that the radiation dose can be reduced three-fold by replacing an aluminum shield by a composite shield of the same total mass that incorporates an inner lining of lead.

Geometrical Transformation for Electron/Photon Transport Calculations (S. M. Seltzer)

An approximate procedure has been developed to transform depth-dose distributions in simple slab targets so as to obtain the spatial distribution of dose in spherical target configurations for space-shielding calculations. Emphasis is placed on the determination of electron and bremsstrahlung dose, which would otherwise require more costly three-dimensional Monte Carlo calculations. For the electron-bremsstrahlung problems tested, results from the procedure require only a fraction of the computer time and are found to agree to within 10-20 percent as compared to direct, three-dimensional Monte Carlo calculations.

Critical Analysis of X-Ray Attenuation Coefficients 0.1 to 100 keV (E. B. Saloman, J. H. Hubbell, & M. J. Berger)

X-ray attenuation coefficients extending into the soft x-ray region, down to 0.1 keV, are increasingly required for the analysis of material properties by techniques such as XRF (x-ray fluorescence), PIXE (proton or particle induced x-ray emission), and electron microprobe analysis. Measured x-ray attenuation coefficient data from the published literature and from other sources are collected on a continuing basis by the NBS Photon and Charged Particle Data Center. These approximately 20,000 data points, covering the photon energy range 10 eV to above 10 GeV, have recently been computerized, and also documented in an indexed bibliography of about 500 source references. A comparison has been carried out, in both graphical and tabular form, over the energy range 0.1 to 100 keV between the above experimental data base and two other photoionization cross section data sets. One of these is a recommended semi-empirical set (0.03 to 10 keV) by Henke et al., and the other is the theoretical set (1 to 1500 keV) calculated by Scofield using a Hartree-Slater atomic model, and extended by Scofield at our request down to 0.1 keV. There has been some disagreement over whether Scofield's results should be subject to Hartree-Slater-to-Hartree-Fock renormalization. The present comparisons suggest that the renormalization does not improve agreement with measurements, at least in the majority of cases. The comparisons identify materials and energy regions where measurements are poor or non-existent, also where present theoretical models are inadequate, such as near absorption edges.

Critique of X-Ray Attenuation Coefficient Measurement Techniques. The International Union of Crystallography X-Ray Attention Project (J. Hubbell)

Crystallographic analysis in either routine industrial or in research applications requires reliable photon cross section data for quantitative interpretation of diffracted x-ray intensities. For a number of technically important materials such as silicon and copper, photon cross section evaluations by the NBS Photon and Charged Particle Data Center have disclosed discrepancies between measurements well in excess of claimed uncertainties, and between available measured and theoretical x-ray attenuation coefficients. As proposed by the Data Center, the Commission on Crystallographic Apparatus of the International Union of Crystallography inaugurated an X-Ray Attenuation Project, for which the Data Center serves as Secretariat, aimed at resolving the serious discrepancies in the data in the literature. The Project Chairman D. C. Creagh (Australia) has fabricated well-characterized absorber samples of silicon, copper, carbon and germanium and distributed them to 23 cooperating laboratories in 11 countries for measurements of x-ray attenuation coefficients using different techniques. Several of these new measurements have now appeared in the published literature. The first Project report, co-authored with Project Chairman Creagh and now accepted for publication in Acta Crystallographica A, presents and compares results for single-crystal silicon measurements by 12 laboratories using eight different experimental configurations. Of these configurations, in the region 4 to 50 keV the preferred arrangement appears to be a stable x-ray tube source, followed by a collimator, the absorber sample, a diffraction crystal monochromator, another collimator, and an Si(Li) detector with associated multi-channel analyzer. Comparison also of these measurements with available theoretical cross sections suggests that for such a highly-ordered substance as single-crystal silicon, in the regions 25 to 50 keV discrepancies of 5 to 8 percent can be removed by replacing the Rayleigh (coherent) scattering cross section with thermal diffuse scattering in compositing the theoretical x-ray attenuation coefficient.

Charged-Particle Spectra and Kerma Factors (J. J. Coyne, H. M. Gerstenberg, R. S. Caswell, & E. J. Axton)

Methods have been developed for the systematic tabulation of the energy spectra of charged particles released in neutron interactions with tissue or tissue-equivalent solids and gases. The spectra treated include both the initial spectra resulting from the nuclear interactions and the energy-degradation spectra resulting from the inelastic Coulomb scattering of the released charged particles as they slow down to rest. The computational apparatus has been prepared for an extensive compilation which will be useful for biophysicists engaged in the modeling of radiation effects. Kerma factors (which are in effect energy-weighted integrals over the initial spectra) have been calculated for H,C,N and O in neutron energy bins 200 keV wide, covering the region from 0 to 20 MeV, and also for 76 logarithmic bins extending from thermal energies to 2 MeV. The information generated includes the contribution to the kerma factors from different particles and from different reactions. A study of cross sections and kerma factors in carbon, particularly above 5 MeV, is being carried out using a least-squares analysis method including correlations.

Microdosimetry for Neutrons (J. J. Coyne; H. M. Gerstenberg; R. S. Caswell; & W. Wilson, Pacific Northwest Laboratory)

The analytical transport theory developed at NBS uses the continuous-slowing-down approximation to calculate energy deposition in small sites by secondary charged particles released in neutron interactions with tissue. Efforts are now underway to refine the method by including the effects of energy-loss straggling of protons, and the effects of energy transport by secondary electrons released in proton-impact ionization events. Two approaches are being used: (a) the incorporation of straggling information into the analytical method; and (b) independent Monte Carlo calculations. Measurements and calculations for cavity sizes much smaller than 1 micron show that the effects of transport of secondary electrons outside the cavity become much more important. A joint project with Pacific Northwest Laboratory to do microdosimetry calculations using proton particle track structure results is underway.

II. Radiation Chemistry and Chemical Dosimetry Group

The program of the group deals with kinetic and mechanistic investigations of radiation effects in chemical and biological systems, from the early physical interaction of radiation and matter to final biological end points, and the dosimetry of radiation effects at various steps. Visiting personnel are indicated with an asterisk.

A. Radiation Chemistry (M. G. Simic, W. L. McLaughlin, E. P. Hunter, L. R. Karam, M. M. Dizdaroglu, D. S. Bergtold*, M. AlSheikhly*, & M. F. Desrosiers*)

The associated chemical and biological processes are studied from a kinetic and mechanistic point of view at a molecular level. That approach requires investigation of transient free-radical species by fast kinetic techniques (pulse radiolysis), product measurement by a variety of analytical techniques (GC/MS, HPLC, spectroscopy, etc.), and characterization of bio-effects by suitable bio-chemical techniques (centrifugation, electrophoresis, chromatography, etc.). The investigations are conducted in both simple and complex model systems, as well as in cells. Cells are used because no model systems can mimic the microenvironment of DNA in living systems.

The major emphasis of the research is on damage and repair of DNA. Since DNA is associated with proteins (histones) and is attached to membranes, some aspects of radiation chemistry of amino and fatty acids also are being investigated.

DNA (M. Dizdaroglu, L. Karam, D. Bergtold*, S. Jovanovic*, & M. Simic)

The research has been focused predominately on the mechanisms of DNA base damage, crosslinking of DNA with proteins, and the measurement of the resulting products. Crosslinking appears to be one of the major effects in cells. The mechanisms and consequences of crosslinking, however, are not yet understood because of measurement problems. The measurement of products of DNA damage (e.g. thymine glycol, 8-hydroxy-guanine, etc.) is utilized for the development of post- irradiation biochemical and biological dosimetry. Irradiation parameters (dose, dose rate, temperature, state, O_2, etc.) are of critical importance since the effects of radiation can be qualitatively and quantitatively altered by them. The effects of quality of radiation (LET) are not investigated at present. However, the study of the effects of low energy protons and α-particles, as well as high energy high Z nuclei (BEVALAC), are in a planning stage.

Relevance and Impact. This research is expected to have an impact in radiation biology, radiation therapy of cancer, cancer etiology, risk assessment, and radiation protection. Specifically, it is relevant to: assessment of damage by low-LET radiations (γ- and x-rays, electrons) vs. α-particles (e.g. radon), and development of standards for individual biological sensitivity to radiation. Unique facilities and expertise at NBS provides new approaches in the study of the biological effects of radiation.

Proteins and Subcomponents (L. Karam, M. Desrosiers*, M. Dizdaroglu, & M. Simic)

The research has been focused predominantly on the hydroxylation of aromatic amino acids and dimer formation induced by radiation. The measurement methodologies for hydroxylated products (e.g. o-Tyr) and dimers have to be developed for ppb quantities in the presence of large numbers of other products and amino acids.

Relevance and Impact. This research is relevant to safety assessment of irradiated foods and the development of post irradiation dosimetry.

Lipids (M. AlSheikhly* & M. Simic)

Mechanisms of radiation induced autoxidation of lipids are being studied by pulse radiolysis and oxygen uptake (utilizing oxygen electrode) in aqueous solutions. Since irradiation of aqueous solutions provides a definable number of initial reactive species, it is possible to measure accurately the length of chain reactions. Pulse radiolysis measurements provide kinetic and spectroscopic parameters of the relevant lipid transients.

Relevance and Impact. Autoxidation of lipids is relevant in meat irradiation processing and the storage of foods. Pulse radiolysis measurements in meats provide important kinetic information lacking so far.

Antioxidants (E. P. Hunter, S. Jovanovic*, M. AlSheikhly*, M. Desrosiers* & M. Simic)

The kinetic and mechanistic features of natural and man-made antioxidants are not fully understood. Pulse radiolysis measurements provide important features (kinetic parameters, redox potentials) for the selection of the most suitable antioxidants for a particular system. The experiments conducted are geared toward acquisition of such predictability. The emphasis is on phenolic and heterocyclic antioxidants and their reaction with DNA, protein and lipid radicals.

Relevance and Impact Antioxidants act as radioprotectors and anticarcinogens and in both cases the mechanism of action is not understood. The impact of this work is in food preservation, protection from radiation and chemical carcinogens, and human physiology. NBS is the only institution in the U. S. dealing with the kinetic aspects of antioxidants.

Chemical Dosimetry (W. L. McLaughlin, M. G. Simic, B. Radak*, M. AlSheikhly*, L. Karam, M. Desrosiers*, M. Farahani*, W. Warasawas*, M. Khan* & M. Hussmann*).

The NBS mission to develop and apply the most appropriate radiation measurement systems to the nation's needs requires that novel chemical systems be explored and tested in practice for that purpose. Chemical reactions are appropriate for both steady-state and real-time dosimetry. A carefully selected group of chemical systems is being investigated systematically in terms of kinetic and mechanistic properties in order to design novel and successful dosimeters relevant for many radiation measurement requirements in fields of current interest, e.g. clinical and diagnostic medicine, agriculture, electronics, materials, environmental technology, space and defense, and radiation protection. Efforts are also being made to develop accurate and precise chemical dosimeters as marketable SRM's for particular nationwide applications.

Underway is a program of applied research on chemical dosimeters for (a) wide dose-range applications (10^{-2} to 10^{8} Gy); (b) mixed radiation fields (low and high-LET fields, e.g. gamma-rays plus neutrons, and charged particles); (c) reference-standard transfer systems (calibrations).

Steady State Dosimetry (W. L. McLaughlin, M. Farahani*, W. Warasawas*, & M. Hussmann*)

A group of chemical systems has been singled out for practical use over wide dose ranges of interest in radiation applications. Those being developed and applied include several inorganics (dichromate solutions, alkali halides, and glasses) and organics (plastics, dyed plastics, aromatics; polycyclic systems; radiochromic solutions; optical waveguide systems). It is also important to find solid answers to problems in the accurate measurement at both high and low doses of mixed field radiations in environmental and personnel protection, medicine and research (e.g. accelerator beams); as well as a wide variety of industrial and agricultural applications.

Real-Time Dosimetry (W. L. McLaughlin, B. Radak*, W. Warasawas*, & M. Khan*)

Convenient active dosimeters are lacking for many applications, in particular, for in-vivo measurements during radiation diagnostics or therapy and for remote telemetering applications in industrial processing. Optical waveguide dosimeters should be developed for medical applications, in order to help solve the sparing of healthy tissue and more effective clinical use of radiation. Solid-state dosimeters are being developed as telemetering systems to control and improve the quality of industrial radiation processing. These include the development of certain semiconductors and calorimeters tied to radiation resistant transmitters. Such systems may also prove valuable for high-resolution radiation imaging as real time devices. They may also have practical use in space and defense applications.

Chemical Dosimetry Mechanisms (W. L. McLaughlin, M. G. Simic, M. AlSheikhly & M. Khan*)

In many instances, the mechanisms of potential and/or proposed chemical dosimeters are not understood. The mechanisms are most conveniently studied by pulse radiolysis, which also provides information about the kinetics and activation energies. For example, complete kinetics and mechanistic description of a widely-used dosimeter in irradiation technology, based on the radiation-induced conversion of radiochromic dyes from the leuco form (no color) to the developed dye (bright, strong color), is not presently available. In particular, the effect of irradiation parameters (concentration, dose, dose-rate, atmosphere, dielectric constant of the solution, temperature, etc.) is of critical importance for the development and ultimate acceptance of a dosimeter as a standard.

These studies would assist in the development of new and specific chemical dosimeters for application in industry, defense, space program, medicine, and radiation protection.

Post Irradiation Dosimetry (PID). (L. Karam, M. Desrosiers*, M. Simic)

There are numerous instances when the knowledge of the delivered radiation dose is required either immediately or long after the exposure. For example, proof that suspected foods have or have not been irradiated is required by food processors and wholesalers for purposes of regulation of import/exports. Reliable measurements which can indicate that irradiated foods have not received radiation dose in excess of the legal limits are needed by regulatory agencies. The discovery of o-Tyr in irradiated chicken meat may be utilized for the development of suitable PID for meats.

Accidental exposure of personnel to radiation has occurred in some cases without an adequate on-line dosimeter being present, accentuating the need for the development of novel concepts in real-time dosimetry and PID for such circumstances.

Measurements of the total energy delivered (J) to a patient in radiation therapy would be useful information to a therapist. The possible presence of unique radiolytic products, URPs, or specific markers, in the urine of irradiated patients or personnel in space (e.g. thymine glycol, 5-hydroxymethyl uracil, etc.) is under investigation.

Achievements

DNA

1. Radiolytic products of DNA base damage can be measured with a newly developed GC/MS methodology at a 10-100 fmol level. The ion select approach is 10-100 times more sensitive than previously utilized methodologies. (Dizdaroglu, Bergtold)

2. Redox potentials of DNA bases, hitherto not known, were determined by pulse radiolysis. These are important in the assessment of oxidative damage to DNA and intramolecular energy cascade within DNA. (Jovanovic, Simic)

3. Guanyl and adenyl radicals which are generated on one electron oxidation of the corresponding DNA bases, in contrast to OH radical adducts, were found not to react with oxygen. This unexpected phenomenon has been explained by strong delocalization (resonance) of the unpaired electron of the radicals. (Jovanovic, AlSheikhly, Simic)

Proteins

Redox properties of tryptophan, one of the essential amino acids, were determined and the mechanisms of intramolecular electron transfer between Trp and Tyr were described. This is important for the understanding of the direct action of radiation on proteins. (Jovanovic, Hariman, Simic)

Lipids

Chain autoxidation of linoleic acid has been investigated as a function of concentration and temperature in aqueous solutions by measuring oxygen consumption. A steep increase in chain length observed above 45°C may be an important factor in hyperthermia (cancer therapy) where cells die also at an increased rate above the same temperature. (AlSheikhly, Simic)

Antioxidants

1. Redox potential E_7=0.36V was measured for 5-OH-Trp. Antioxidants of this class have been suggested by the author as endogenous physiological antioxidants. They may protect neural receptor sites and act as radioprotectors as well. (Simic, Jovanovic)

2. Neutralization of peroxy radicals by sulfhydryls has been found to be a redox process. This observation contrasts previous beliefs that sulfhydryl radioprotectors act as H atom donors. (Simic, Hunter)

Steady State Dosimetry

1. Advances in the development of optical waveguide (OWG) dosimeters have been made for the following specific applications: (a) in-vivo medical dosimetry in real time; (b) pulse-radiolysis dosimetry at low

doses per pulse; (c) food irradiation dosimetry; (d) emergency dosimetry. This work is supported in part by the Federal Emergency Management Agency. (McLaughlin, Radak, Warasawas)

2. Work is continuing in the development of important SRM chemical dosimetry systems for high-dose applications in industrial radiation processing. These will greatly assist industrial radiation users to achieve measurement quality assurance, for example, in the radiation sterilization of medical devices and the radiation treatment of foods. (McLaughlin)

3. Novel chemical dosimeters have been developed at NBS for practical applications over wide dose ranges (10^{-3} to 10^{8} Gy). These include: (a) sublimation systems (e.g. camphor, thymol, borneol); (b) polyethylene; (c) bromophenol blue; (d) dyed and undyed polyhalostyrenes. International dosimetry intercomparisons of some of these systems, along with calorimetery and conventional radiochromic dosimeters, are being conducted to determine their best utilization. (McLaughlin, AlSheikhly, Warasawas, Hussmann)

Chemical Dosimetry Mechanisms

1. The mechanisms of radiolytic dye formation, which constitutes the largest commercial utilization of chemical dosimetry, are being successfully explored for the first time. Pulse radiolysis is providing data which may explain how these systems respond in terms of dye yield, without undergoing rate dependence of response. (AlSheikhly, McLaughlin, Farahani)

PID

The discovery that o-Tyr, a suggested marker for irradiation treatment of meat, is present in unirradiated chicken breast made its use in PID questionable. o-Tyr, however, was not found in the unirradiated meat fiber, indicating its presence only in the sarcoplasm of meat. On irradiation, o-Tyr was found in the meat fiber, providing a base for the development of a first PID for meats. (Karam, Simic)

III. Neutron Measurements and Research

This group is concerned with measurements of neutron interactions which depend strongly on the neutrons' energy. The interactions require neutron spectroscopic capability from 0.005 eV to 50 MeV--over ten decades of energy. The largest program is devoted to a continuing international effort to push the accuracy of reference neutron cross sections into the ±1 percent (1 SD) range. Although the group has made significant contributions to this effort, much work remains in selected neutron energy regions to achieve this important goal. This activity, which is jointly supported by the U.S. Department of Energy, includes both an extensive experimental effort as well as coordination of the evaluation of the neutron cross section standards for the United States. These standards form the basis for nearly all neutron nuclear data since these data are measured relative to the standards. Hence they supply large leverage since an improvement in the accuracy of the standards will improve the accuracy of the entire data base without an extensive remeasurement effort. Other programs are concerned with the development and exploration of analytical techniques based on the unique features of the neutron's interaction with matter. Both the standards and analytical studies require a significant component of fundamental neutron research. The group possesses the unique combination of highly trained technical staff and research facilities to continue to produce significant leadership in these areas. The NBS facilities used are the 100-MeV linac dedicated pulsed neutron source, 3-MV positive ion electrostatic accelerator, 100 keV neutron generator, and nuclear research reactor. In response to requests from other programs within NBS, a 6-MeV γ-ray radiation facility and a Rutherford Backscattering Analyzer for surface studies have been implemented at the positive-ion accelerator. A technical description of the group's activities and significance of its success in completing projects follows.

$^{235}U(n,f)$ Cross Section from 0.02 to 1000 Electron Volts (R. A. Schrack)

The Neutron Measurements and Research Group has undertaken a measurement of the shape of the neutron induced fission cross section from .02 to 1000 eV where there have been large discrepancies (on the order of 7 percent) in the reported values of these integrals. This measurement is being undertaken to help resolve the current discrepancies in this important cross section standard.

Measurements made here with the uranium-boron fission chamber in late 1985 indicated that the configuration of the chamber caused the energy resolution of the uranium fission chamber to be much poorer than that of the boron chamber. This difference in resolution caused errors in the uranium cross section calculation. The chamber was redesigned to eliminate geometrical sources of resolution broadening. There are now two separate uranium fission chambers together with the boron chamber in the same housing. All chambers now have separate electrical connections to implement this important development. Measurements made with the new chamber confirm its improved resolution and flight-path compensation.

To verify the understanding of the chamber operation, a computer program was developed to synthesize the resolution of the system, taking into account the time distribution of the neutron generation as well as the spatial distribution of the uranium and boron foils. Using this synthesizer code together with a data analyzer code, the proposed experimental measurements of the uranium integral cross sections were simulated. These simulations enabled one to determine the errors induced by various parameter changes. The results of these studies were used to select the parameters for the experiments.

Detailed studies and preliminary diagnostic measurements indicate that all major sources of background and electronic drifts have been understood. The uranium-boron fission chamber is now at a point of development to begin long runs at the dedicated-pulsed neutron source to acquire the data leading to a more precise measurement of the ^{235}U fission cross section.

<u>Acquisition of a Microcomputer System</u> (R. A. Schrack)

The Neutron Measurements and Research Group has acquired an AT&T PC6300 microcomputer to provide additional computational and editorial facilities for the members of the group. A survey of the available types of "IBM-compatible" personal computers was made in collaboration with other computer users at the Bureau. In addition to determinations of reliability and operational convenience, an extensive comparison was made of computational speed and accuracy. A variety of program types were run to test the relative speed of simple operations, access time, etc. The relative merits of the different computers tested varied slightly from one test to another. A widely used test that reflects the different test results is the Sieve of Eratosthenes (an algorithm for finding prime numbers). The table below shows the results obtained for this test.

Speed of Computers Relative to the IBM PC/AT

	IBM PC/AT	IBM PC/XT	Deskpro	AT & T 6300
microprocessor	(80286)	(8088)	(8086)	(8086)
without coprocessor	1.00	2.54	1.17	1.12
with coprocessor	1.00	1.18	0.63	0.58

It should be noted that the speed of the PC/AT with the coprocessor is 16 times greater than the speed without the coprocessor. From the tabulated results one can see that when used with a coprocessor the two 8086 computers had greater speed than the 80286 computer. This is a surprising result and is caused by the relatively inefficient coprocessor available for the 80286. In addition to the speed advantage there is a price advantage; for the 8086 computers, that is considerable. In addition, the AT & T computer has twice the screen resolution of any of the other machines. The group has purchased the AT & T computer and found it to be compatible with all commercial software.

Multi-Particle Accelerator for Neutron and High-LET Radiation Research (R. G. Johnson)

In June 1986 the IAEA sponsored an advisory group meeting in Leningrad, USSR on neutron source properties. The final report on the preliminary design study of a linear induction accelerator for neutron and high-LET radiation research was presented at this meeting.

This preliminary design study was carried out as part of the analysis of neutron and high-LET radiation research program at NBS conducted by the Center for Radiation Research staff. Subsequent to that program analysis, the accelerator design study has been updated to include the most recent technological advances for induction linacs.

The developments in this technology both before and after our initial study have significantly improved the practicality of induction linacs for moderate-energy high-current accelerator applications. Of primary significance is the development of magnetic pulse compression techniques and the related development of iron-based metallic glasses.

The target parameters of the preliminary design were chosen with many considerations in mind and represent in most cases only modest requests of the technology. The accelerator was designed to accelerate up to 250 A of electrons to 100 MeV with a pulse structure of 100-ns maximum length at repetition rates up to 1000 Hz. Because of the versatility of induction linacs, protons and other light ions can also be accelerated with currents limited only by space charge effects. The design includes provision for accelerating protons and deuterons at maximum currents of 2.5 A and 1.2 A, respectively.

This accelerator would be a powerful and versatile tool for neutron and high-LET radiation research. Both continuous and quasi-monochromatic beams of neutrons would be available and the light ions could be used directly.

Data Acquisition Computers (R. G. Johnson)

FY-86 was the first year of operation without a maintenance contract on the three Harris /5 data acquisition computers. Although we have been able to keep all three computers running, implementation of replacement systems is becoming critical. The computer system chosen for the replacement is a Charles River Data Systems UV2403FT computer. This computer is based on the Motorola MC68000 microprocessor and the VME bus. Following the initial purchase of one of these systems (delivered in October 1985), the purchase of two additional boards have completed the basic hardware. The first of these boards provides the interface between CAMAC and the VME bus. The second board contains 4 Mbytes of error correcting memory which will allow two-parameter data to be stored in memory.

The CRDS computer has been installed in the counting room used for linac neutron measurements and the software (written in assembly language) for the CAMAC-VME interface has been entered into the computer. Several European laboratories, most notably CERN, have adopted very similar hardware for data acquisition. Consequently software for the interface is public domain. Testing of the software has just been started. After validation of the interface drivers, the data acquisition software which will be written in a higher-level language (FORTRAN and/or C) can be written.

In FY-87 a request for a second computer system, needed for positive ion accelerator neutron measurements, will be made.

<u>Detectors for Neutron Scattering in the eV Region</u> (R. G. Johnson)

In the last few years a new source of neutrons for condensed matter studies has been developed at several facilities around the world. These sources are based on high-current high-energy proton accelerators which produce neutrons by spallation. The facilities which are now partially or fully operational include: IPNS at Argonne National Laboratory, KENS at KEK in Japan, WNR-PSR at Los Alamos National Laboratory, and SNS at Rutherford Appleton Laboratory in the UK.

Since these new sources are accelerator-based, they are by nature pulsed. Consequently, instruments using neutron time-of-flight are being developed to take full advantage of this characteristic. Furthermore, to preserve the time structure, the neutrons are lightly moderated as compared to steady-state reactor sources. Although there is disagreement on how to compare reactor sources with the new pulsed sources in the thermal region, it is clear that the new sources provide much higher fluxes of neutrons in the eV region.

Traditionally neutron scattering measurements have been confined to energies below a few hundred meV primarily because of the rapidly decreasing flux from fission reactors above these energies. Spallation neutron sources on the other hand provide a high flux of neutrons well above 1 eV. It is expected that the opening of this energy range to condensed matter studies will provide information to many fields. The studies which may be interesting have been the subject of several reviews and a recent international workshop. However, considerable instrument development is necessary before full advantage of measurements at eV energies can be realized. The instruments developed for reactor sources are not in most cases suitable for extension to the eV region.

One of the general methods to extend inelastic neutron scattering measurements to higher energies is to use low energy neutron resonances to define one energy in the scattering process. The other energy can be defined by neutron time-of-flight. This general method can be implemented in several ways in direct geometry (monochromatic energy defined before the scattering) or indirect geometry (monochromatic energy defined after the scattering). In these studies in our group a particular method in indirect geometry is investigated. Specifically, since resonances of interest are primarily capture resonances, a foil of the material which has the desired resonance is placed next to a detector which detects prompt capture γ rays (or other secondaries). This instrument is called a Resonance Detector Spectrometer (RDS).

Capture resonances in the eV range occur in medium to heavy nuclei. Prompt γ rays following capture have a complicated spectrum with energies up to the binding energy of the added neutron, typically 6-8 MeV. The intensity of the γ lines falls by an order of magnitude as the energy increases. Secondary radiation in the form of electrons and x rays are created since many of the low energy γ lines have high internal conversion coefficients. As with most detectors, desirable qualities of detectors for RDS are high efficiency and good background rejection. Two promising candidates for such detectors have been tested here: a bismult germanate (BGO) scintillator and a high-purity germanium (HPGe) detector. The BGO scintillator is used to detect prompt capture γ rays while the HPGe detector is used to detect low energy γ rays and secondary x rays.

To test these detectors simple recoil scattering from an aluminum sample at 90° was used. Three different resonance foils were included in the tests: indium (1.457 eV), tantalum (4.28 eV), and gold (4.906 eV). The tests were performed using the Neutron Time-of-Flight Facility (NTOFF) at the NBS Dedicated Pulsed Neutron Source.

Recently a method which improves the signal to background ratio for the HPGe detector has been implemented. The method relies on the fact that in the internal conversion process both an electron and an x ray are emitted. By detecting the electron with high efficiency in coincidence with the x ray an improvement in the signal to background ratio of 5.5 has been observed.

The principal conclusion of these studies is that the planar HPGe detector appears to be the best detector for future developments in RDS instruments.

International Intercomparison of Neutron Flux Measurement Capability at 500 keV (A. D. Carlson, R. G. Johnson, & O. A. Wasson)

A final report on the NBS participation in an international intercomparison of neutron flux measurement capability sponsored by the Consultative Committee for Ionizing Radiations (CCEMRI) at BIPM was prepared and sent to AERE Harwell, the organizing laboratory last year. This intercomparison which uses a large ^{235}U fission ionization chamber allowed both linac and 3 MV Positive Ion accelerator neutron facilities to be used. The detector efficiencies measured at 500 keV at the linac and facilities at NBS agree well within the 1.7 percent total error for each measurement. During the past year measurements have been completed at three additional laboratories to bring the total participation to seven laboratories. It is anticipated that this intercomparison will be completed during the next year and that the analysis of the results will lead to an improvement in the $^{235}U(n,f)$ standard cross section.

Development of a Radiation Spectrum Unfolding Capability on the NBS Central Computer (K. C. Duvall)

A general capability to conduct Radiation Spectrum Unfolding analyses has been established on the NBS Central Computer. The spectrum unfolding analyses, which requires a substantial allocation of computer memory, significantly benefits from the increased computing power of the new NBS high-speed super computer. A fairly extensive collection of computer codes has been assembled for the spectrum unfolding analyses consisting of routines to generate NaI, Dual Thin Scintillator (DTS), and Black Detector response functions, two spectrum unfolding routines including the widely recognized FERDoR code (developed at Oak Ridge National Laboratory), a least squares fitting routine, a routine to generate simulated detector data, and several data handling routines. The programs are currently running in the interactive and batch mode on the Cyber 855 and the Cyber 205 super computer. The spectrum unfolding capability has been utilized thus far for analysis of gamma-ray and neutron radiation spectra, for both monoenergetic and continuous sources, using measured and simulated pulse height data. A typical large problem analyzed was 255 pulse height channels and 90 energy bins. Considerable effort has been devoted to developing the expertise required to properly formulate the unfolding problem in terms of determining the appropriate energy versus pulse height mesh, smoothing, gain and zero adjustment of data, and 'a priori' constraints for each specific problem. Although peculiarities are evident in each particular problem, the analysis package has been developed with enough flexibility to handle a large class of radiation spectrum unfolding problems. It is expected that a number of refinements and improvements in the software package will continue.

The development of a Radiation Spectrum Unfolding capability on the NBS central computer originated as a result of the need to unfold NaI pulse height data for characterization of the NBS 6 to 7 MeV photon field and also because of the recent interest in the DTS detector for neutron spectrum unfolding. In neutron spectral determinations, spectrum unfolding is applicable when timing information is not available for utilization of time-of-flight methods. Some spectral determinations in which spectrum unfolding is applicable are in measurements involving passive detectors such as activation foils, slow response detectors such as moderating devices, and spectral determinations at small source to detector distances. The Radiation Spectrum Unfolding analyses is expected to be increasingly useful as the interest in high energy CW accelerators for production of high yield gamma-ray and neutron sources grows. The spectra produced from high energy beams generally contain less structure and a larger contribution from broad energy continua which usually result from interactions of high energy electrons and break-up reactions. Spectrum unfolding methods are well suited for analysis of broad slowly-varying spectra.

Developments in the Characterization and Utilization of the Dual Thin Scintillator (K. C. Duvall)

The development of new and improved radiation measurement methods is essential for achievement of higher accuracy standard cross section data. The DTS is a unique detector being developed independently here at the NBS for neutron flux and spectrum measurements in the 1 to 15 MeV energy region. Currently, most high accuracy neutron flux determinations in this energy range rely on measurements with proton recoil telescopic (PRT) devices which suffer from extremely poor sensitivity. The DTS detector may be utilized to obtain a high accuracy neutron flux determination while maintaining a good sensitivity to fast neutrons.

Further improvements in the DTS response have been recognized when the detector is operated in the sum coincidence mode which produces a highly peaked response function. The peaked response function provides an improvement over the conventional rectangular response function normally obtained with thin organic scintillators by allowing better peak channel definition and extrapolation to zero pulse height.

The unique detection mechanism employed in producing the DTS sum coincidence response is also of interest. Present detection processes used to overcome the poor characteristics of the rectangular response function modify the proton recoil energy distribution by geometrical constraints (PRT) which suffer from poor sensitivity or by total absorption (Black Detector) which requires large detector dimensions. The DTS sum coincidence response utilizes the constraint of the recoil particle range to restrict the detector geometry without significantly reducing the detector sensitivity. Although a Monte Carlo calculation of the DTS response is available, a detailed analytic evaluation of the sum coincidence response characteristics has been done. The analytic approach has allowed the detection process in the DTS sum coincidence mode to be better understood and has been instrumental in identifying areas of further improvement.

Another important area being investigated for DTS detector utilization is in neutron spectrum unfolding. The peaked response function obtained with the DTS sum coincidence is expected to provide a significant improvement over spectrum unfolded results produced with the conventional rectangular response functions. Although spectrum unfolding methods are considered well established, an extensive search of the literature indicates that neutron spectrum unfolding methods have been applied almost exclusively to the rectangular response functions of organic scintillators. We have therefore undertaken a program to compare spectrum unfolded results from DTS rectangular and sum coincidence response functions. The widely recognized FERDoR unfolding code (developed at Oak Ridge National Laboratory) is being utilized along with the calculated DTS response functions and simulated pulse height data.

The objective is to verify the dependence of spectrum unfolded results on response function shape, determine the magnitude of the effect, and further understand the mechanism behind the expected error amplification associated with the response function shape. Preliminary results have indicated that differences in unfolded results can be observed for identical problems using different response functions. A result that was rather unexpected is that the spectrum unfolded results depend not only on the shape of the response functions, but also on the detector efficiency curve. The optimum detector for use with spectrum unfolding analyses would therefore have peaked response functions and a steeply decreasing efficiency with increasing neutron energy.

Utilization of the NBS Dual Thin Scintillator Neutron Detector for Activation Cross Section Measurements (K. Zasadny, G. F. Knoll, U. of Michigan; O. A. Wasson, R. G. Johnson & K. C. Duvall)

The value of the Dual Thin Scintillator Neutron Detector for precise neutron fluence measurements in the 1-15 MeV energy region continues to be recognized by other laboratories. This detector is being used to determine the neutron fluence incident on the samples for new 14 MeV neutron activation cross section measurements at the 125 beV neutron generator facility at the University of Michigan. Previous measurements were compared to a commonly used $^{56}Fe(n,p)$ reference cross section. These new measurements will combine these techniques and further reduce the systematic errors which will produce more accurate cross sections. These cross sections are applied in many areas of neutron dosimetry and spectral measurement.

Neutron Detector Characterization (K. Kudo, ETL, Japan & A. Carlson)

Measurements have been made of the response of a neutron detector which should become a standard for the determination of neutron flux (fluence) in the MeV neutron energy region. The detector provides good timing and pulse height unfolding capability.

Measurements have been made in the MeV energy region of the neutron response functions of this 5 cm diameter x 5 cm thick NE-213 detector at the NBS linac neutron time-of-flight facility. The detector has also been studied experimentally at PTB, Braunschweig, W. Germany and ETL, Ibaraki, Japan. These measurements should allow a determination of the consistency of results obtained under different experimental conditions and comparisons with calculated response functions. The present measurements were obtained in a two-parameter mode (pulse-height and time-of-flight). The neutron flux determined from the time-of-flight data will be compared with the result obtained from unfolding the pulse height data.

International ^{235}U Fission Foil Mass Intercomparison (I. Schröder, D. M. Gilliam, A. D. Carlson, S. W. Bright, & J. M. R. Hutchinson)

In the measurement of neutron fission cross sections, one of the larger uncertainties is associated with the mass determination of the fissionable deposit. Inconsistencies in determinations of the fission cross sections may be a result of systematic errors associated with the measurement of the deposit mass.

As part of a study to check the consistency of mass scales at a number of laboratories throughout the world, two ^{235}U deposits from the Khlopin Radium Institute (KRI) in Leningrad, USSR were made available through the assistance of the IAEA for measurements at NBS and ANL. These deposits are directly traceable to foils used in very precise measurements of the ^{235}U(n,f) cross section made in a collaborative effort by KRI and the Technical University of Dresden (TUD), GDR.

The study undertaken at the NBS consisted of two parts. One consisted of the measurement of the alpha-decay rates of the two ^{235}U samples (KRI VI and KRI-XV) with a low geometry counting spectrometry facility. The other consisted of the measurement of the total alpha disintegration rate of the samples employing a 2π alpha-counter.

A comparison of the ^{235}U mass determinations shows that the NBS results by the two separate methods, the low geometry results from ANL, and the KRI values all agree within their stated uncertainties. In addition, Poenitz has determined values for the KRI samples based on an intercomparison of measurements of foils from a number of contributing laboratories. The input data included the masses quoted by the contributing laboratories, masses derived from low geometry alpha counting and relative 2π

alpha and fission ratio measurements. The values he obtained in this evaluation are 760.2 ± 1.4 for KRI-VI and 893.0 ± 1.8 for KRI-XV. The outcome of the KRI mass scale determination will have a direct effect on the KRI-TUD fission cross section measurements and their uncertainties. This effort should contribute to the long-sought objective of 1% accuracies for this cross section.

$^{235}U(n,f)$ Measurements from 3-25 MeV Neutron Energy (A. D. Carlson, O. A. Wasson & P. W. Lisowski, LANL)

There is a need for improved measurements of the $^{235}U(n,f)$ cross section in the upper MeV energy region where this cross section standard is not well known. An experiment is planned at the new white source facility at WNR (Target-4) in LANL. This source will be capable of producing very intense beams of high energy neutrons which are required for this measurement. The portion of the Target-4 facility construction which is required for this experiment is expected to be completed late this summer. The design of the fission experiment has been completed. The various components of the experiment either exist at the present time or are being worked on. However since this is a new facility the entire experiment, including the flight path tube, collimators, end station, and detectors must be set up before experimental tests can be begun. It is expected that the flight path tube, collimators and end station will be in place in September. The fission detector is an existing LANL fission chamber for which new fission deposits are being made at ORNL which are expected in September. The neutron flux detector is an annular proton telescope which was built at NBS. Work is in progress to improve the timing of this detector. The work so far has been focused on conditioning the Si(Li) detector so that it will function at very high voltages so as to reduce the collection time. A protective system for the detector was designed and fabricated.

The first phase of the experiment will involve tests of the detector systems and measurements of fission cross section ratios at the LANL Van de Graaff facility in October. Following this testing period the detectors will be set up at the WNR facility for cross section measurements.

The ENDF/B-VI Neutron Cross Section Standards Evaluations (A. D. Carlson, W. P. Poenitz, ANL; G. M. Hale, LANL; R. W. Peelle, ORNL)

Plans have been made for a new version, the sixth, of the U.S. Evaluated Nuclear Data File, ENDF/B. The individual evaluations are all critically dependent on the new evaluations of the neutron cross section standards. The standard evaluation process for this new version is more thorough and logically consistent than that used in earlier versions. The primary effort is focused on a simultaneous evaluation using generalized least squares, R-matrix evaluations and a procedure for combining the results of these evaluations. The simultaneous evaluation is important to this process since ratio measurements in addition to shape and absolute determinations are treated properly. Correlations within and among experimental data sets are also taken into account. Also the output results from the thermal constants evaluation by Axton, including the associated variance-covariance matrix, has been used as input for this evaluation. The R-matrix evaluations provide a method which allows charged-particle measurements involving the same compound nuclei (^{7}Li and ^{11}B) to be included in the evaluation process. These evaluations also provide a smooth meaningful expression for the energy dependence of the cross sections. Independent data bases are used in the simultaneous and R-matrix evaluations. The combining procedure is used to combine the information obtained from these analyses in a proper way to form the final evaluation and its variance-covariance matrix. The standards being evaluated are ^{6}Li(n,t), ^{10}B(n,α_1), ^{10}B(n,α), ^{197}Au(n,γ), and ^{235}U(n,f). Evaluations for the important reactions ^{238}U(n,γ), ^{238}U(n,f), and ^{239}Pu(n,f) are also being performed.

Considerable progress has been made on this process. One complete "pass" has occurred. The output results from the R-matrix and simultaneous evaluations have been combined successfully. Preliminary investigations indicate that except for the ^{10}B cross sections, the conditions for the combination procedure working properly have been satisfied.

Proposals for handling the ^{10}B cross sections are under investigation. Near final results are expected to be presented at a meeting at ORNL in September 1986. However, smoothing/fitting of the capture and fission data, and phase 1 and phase 2 data testing must be completed before the evaluations will be available for distribution.

Measurements of the ^{10}B(n,α)^{7}Li to ^{6}Li(n,t)^{4}He Cross Section Ratio from 1-100 keV (A. D. Carlson & G. E. Cooper)

The ^{10}B(n,α)^{7}Li to ^{6}Li(n,t)^{4}He cross sections are neutron cross section standards up to ~ 100 keV. It has become clear recently that significant improvements are necessary for these cross sections, particularly for the ^{10}B(n,α)^{7}Li reaction. Significant improvements in the data base will occur with accurate determinations of the cross section ratio. Towards this goal measurements are now beginning at the 20 m station of the NBS neutron TOFF. The experimental set up is similar to that used for the ratio measurements of these cross sections in the eV energy region. The ^{10}B detector is the same one used previously (a ^{10}B plated ionization chamber). The ^{6}Li detector involves the same basic assembly as was used in the previous investigation except the natural Li glass detector has been replaced with one enriched in ^{6}Li. This modification significantly reduces the percentage of gamma-ray background. Exploratory runs are being made to measure the backgrounds, examine detector recovery at high neutron energies, check detector resolution, and determine counting rates.

Advances in the Use of ^{3}He in a Gas Scintillation Counter (J. W. Behrens, Ma Hongchang, IAE, Beijing, PRC; & O. A. Wasson)

For several decades it has been suggested that the ^{3}He(n,p)T reaction should be utilized for detecting neutrons over the entire range from thermal energies to MeV energies. In fact, this reaction has been suggested as a possible standard. The reaction has a Q value of 764 keV and is easily detected in both a gas proportional counter (gpc) and gas scintillation counter (gsc). The use of ^{3}He in gpc's is rather common today; however, its use in gsc's is rare, in spite of the improved timing resolution available from the latter. A possible reason for this is the sensitivity of the uv photons to trace organic impurities in the gas. At the NBS, we constructed a ^{3}He/Xe gsc which operated for over two years on its original high-purity gas fill without any continuous gas purification. This step marks a significant advance toward the possible standardization of the ^{3}He(n,p)T reaction.

Our first gsc was studied at the NBS 10 MW reactor, 3 MV positive ion accelerator, and 120 MeV electron linac over the past two years. The gas mixture of ^{3}He and xenon was contained in a right circular cylinder of length 250 mm and diameter 100 mm. Total pressure of the gas mixture was held constant at 30 psia. Photomultiplier tubes (RCA 8850) were mounted onto the end windows consisting of pyrex glass coated on the cell's inner surface with a 30 microgram/cm^2 coating of diphenylstilbene. The gas mixture was varied from 5 percent Xe to a final 50 percent Xe composition. Light collection more than doubled as the composition was varied, while holding the total pressure at 30 psia.

Light collection degraded less than 10% over the two year period that this gsc was tested. Light collection degradation was determined by comparing the ^{3}He(n,p)T peak with the single-photoelectron peak. The gsc had a resolution of ~ 55 percent (FWHM) on the ^{3}He(n,p)T peak and typically required 25 keV/photoelectron.

Our second gsc contained several improvements. The number of pyrex window/photomultiplier tube modules (pw/pmt modules) was doubled and the cell size was reduced. The cell consisted of a cube with 150 mm sides. Four faces of the cube contained the pw/pmt modules; whereas, the remaining two faces were for neutron beam entrance and exit. With a ^{238}Pu α-source mounted in the center of the cell, with 30 psia xenon, and with 3 pw/pmt modules looking at the source, a resolution of 10 percent (FWHM) was measured for the 5.5 MeV α-particle peak. A total of ~ 800 photoelectrons represented the α-particle peak for a conversion rate of ~ 7 keV/photoelectron. Next, the second gsc was tested using neutrons from the thermal column of the NBS reactor. For this test, a gas mixture of 12 percent ^{3}He, 88 percent Xe was used at a total pressure of 22.5 psia. The gsc had a measured resolution of ~ 32 percent (FWHM) on the ^{3}He(n,p)T peak.

In order to meet the needs of keV-energy neutron cross section measurements, a resolution of $\leq$ 20 percent (FWHM) on the ^{3}He(n,p)T peak is required. This might be accomplished with one further modification to our design. Namely, we would use 10 cm diameter pyrex windows and $\geq$ 7.5 cm diameter photomultipliers instead of the present 3" diameter pyrex windows and 2" diameter (RCA 8850) photomultipliers. Work is presently in progress on incorporating this improvement into our design.

Future measurements at the NBS might include absolute determination of the ^{3}He(n,p)T cross section at 0.5 MeV using the NBS "Black Detector" at the 3 MV positive ion accelerator and at 2.5 MeV using the associated-particle technique at our 200 kV neutron generator. The shape of the cross section could be measured at our 120 MeV linac dedicated pulsed-neutron source using a time-of-flight technique for the neutron energy range from thermal to 3 MeV. Improved gsc performance and accurate measurement of the ^{3}He(n,p)T cross section are crucial steps toward elevating this reaction to a viable standard level.

Topical Fission Conference Planned (J. W. Behrens & O. A. Wasson)

The NBS plans to host a topical conference at its Gaithersburg, Maryland site to acknowledge, "Fifty Years With Nuclear Fission." This conference will be held April 26-28, 1989 and will have both invited and contributed papers from an estimated 250 participants. The NBS presently has the American Nuclear Society as a co-sponsor and will seek other appropriate cosponsors (DoE, APS, etc.). A newsletter, announcing the conference and giving an outline of its scope, will be distributed after January 1, 1987.

Fission Cross Section Systematics (J. W. Behrens)

Work on the fission cross section systematics for a total of over 40 isotopes of uranium, neptunium, and plutonium has been completed. A publication of this portion of the study is near completion and will be submitted to Nuclear Science and Engineering. The work will then continue by extending into the light actinide region where a total of over 20 isotopes of thorium and protactinium will be examined.

IV. Neutron Dosimetry Group

This group is engaged in the development and application of standard and reference neutron fields as permanent facilities for neutron dosimetry standardization, for neutron detector calibrations, and for reaction rate cross section measurements. Strong interactions with outside organizations, both in the federal and private sector, are important programmatic characteristics. Contact for information regarding individual tasks is J. Grundl.

Neutron Personnel Dosimetry (R. Schwartz & D. Gilliam)

Several types of activity are carried on under this rubric. These include use of the NBS standard neutron fields for routine calibrations, for non-routine testing, development, and calibrations of new types of neutron instrumentation, and for quality control measurements of production instruments. As part of a contract with the Armed Forces Radiobiology Research Institute (AFRRI), we have also been developing a tissue equivalent proportional counter (TEPC) system to determine neutron dose as a function of energy deposited, and have designed and directed the building of neutron check source facility.

(1) Routine calibrations were carried on at about the same rate as in previous years and with about the same overall results: for every instrument that reads essentially correctly, there seems to be one that doesn't work at all. Badly calibrated instruments seem to be the rule rather than the exception. For all of these activities, significant improvements in the Californium Irradiation Facility this year have made the system easier and more foolproof to use. Likewise, required documentation for this calibration service has been completed and reviewed up to the Center level. The document is approximately 35 pages long, and includes detailed discussions of the corrections to the data and uncertainties, as well as a description of the facility and the various calibration procedures.

(2) We have been working with Yale University in the development of a new type of neutron dosimeter, and with the Battelle Pacific Northwest Laboratory in the development of a remmeter based on a TEPC.

(3) The first operational tests of our TEPC system were conducted at the AFRRI TRIGA reactor early this year. Although this two day run was only intended to test feasibility, the system ran well enough that useful results were obtained. Neutron data were taken free in air, and in the center of 14-cm and 20-cm diameter phantoms. A lead shield essentially eliminated the gamma dose. As anticipated, attempts to take data without the lead shield were unsuccessful due to the enormously high count rate of the gammas. Also as anticipated, the data clearly showed that the neutron dose rate went down, and the gamma-to-neutron dose ratio went up, as we went from air to thin phantom to thick phantom. This is easily understandable in view of the shielding provided by the phantom, and the gammas produced by radiative capture in the hydrogen of the phantom. The data also showed, however, that the shape of the neutron part of the "y-curves" (i.e., curves of y versus yd(y), where y is the lineal energy and d(y) is the probability density of absorbed dose in y) were essentially identical for the three conditions when properly normalized. This was not at all obvious a priori and the result suggests that future calculational effort might best be spent on understanding the gamma part of the dose, rather

than the neutron, since to first order, the shape of the neutron part does not seem to change. The magnitudes of the neutron and gamma doses can be accurately measured with the appropriate tissue equivalent ion chambers.

Some interesting details in the measured spectra suggest the need for further experimental investigation. Fine structure in the peak of the 20-cm phantom data was just within the 2 percent statistical uncertainty of the data points. Although it is considered unlikely that the structure is real, the measurements should be repeated with higher statistical precision. Also some slight energy shifts among the spectra may not be due to drifts in TEPC gain.

(4) The AFRRI check source cask has been received from the vendor and is now in place in their Standards Laboratory. The californium source was shipped from Savannah River and transferred to the cask by the end of September after some unusual safety, security, and administrative questions had been settled.

(5) New fission chamber monitors for the AFRRI exposure rooms have been fabricated and tested. These monitors will provide a direct measure of neutron exposure over the full range of the Triga reactor dose rates, without sensitivity to gamma ray background. Based on a double ionization chamber arrangement, these monitors will establish exposures with a precision of 1 percent for power levels as low as 1 kW and irradiations as short as 1 minute, or alternatively, will monitor exposure rates at a power level of 1 MW with less than 1 percent deadtime correction.

(6) A meeting of ISO TC 85/SC 2 ("Radiation Protection") was held at the PTB, Germany. At this meeting we saw the final printed version of the ISO Draft International Standard (ISO/DIS 8529) "Neutron Reference Radiations for Calibrating Neutron Measuring Devices ... ." This was the culmination of several years work on the part of the Working Group, and is to be voted on by the Member Bodies of ISO (ANSI, in the case of the United States) by December 5. At this meeting we also pretty much finished a second standard, "Procedures for Calibrating ... Neutron Measuring Devices ... ." Some details need to be worked out, but it is anticipated that these can be settled within the next few months.

The first meeting of the ICRU Report Committee on Practical Determination of Dose Equivalent is to be held in France in mid-September. At this meeting work will begin on a report covering the measurement of dose equivalent in terms of the new specifications for environmental and individual monitoring promulgated by the ICRU.

Dosimetry for Materials Performance Assessment (E. D. McGarry, G. Lamaze, & J. Grundl)

(1) First time ever production of neutron fluence standards with 30-year ^{137}Cs activity occurred this year. Neutron fluence standards are neutron sensors (activation foils generally) in which a radioactive species relevant for dosimetry is induced by irradiation in a standard neutron field. The NBS Cavity Fission Source was used to expose ^{238}U to a certified neutron fluence of about 2×10^{16} n/cm^2 which is sufficient to produce a measurable 30-year ^{137}Cs fission-product activity. These fluence standards are used to verify commercial neutron fluence measurements made with similar uranium foil dosimeters, such as are used in reactor pressure vessel surveillance.

(2) In the past year, requests for benchmark calibrations of sulfur dosimeters have increased. These particular activation dosimeters have been used for many years as a neutron fluence monitor for radiation hardness testing of electronics. To ensure that experimenters at different irradiation facilities are making consistent neutron dose assignments, several facility managers have requested benchmark calibrations with NBS fission neutron sources. This year, sulfur irradiations for AFRRI, Sandia, White Sands, and Aberdeen Proving Grounds have been performed at the Californium Fission Neutron Irradiation Facility. A special feature of sulfur activation is that it emits only beta rays. This complicates the specification of an effective calibration fluence because of the correlation between neutron field gradients and beta absorption in the sulfur detector pellets. Monte Carlo calculations have been performed to calculate a beta absorption vs. gradient correction factor for several different size sulphur pellets.

(3) Quality assurance measurements were performed to verify masses of fissionable deposits used for solid state track recorder (SSTR) neutron dosimeters. SSTR's are mica disks which register tracks of fission fragments from an adjacent fissionable material. Although SSTR's are an attractive technique for doing dosimetry in remote and hostile environments, very small amounts of fissionable material are required and mass determination can be a difficult problem. At NBS mass assay was accomplished by means of a fission rate intercomparison. Back-to-back deposits in a dual NBS fission chamber were compared with NBS Fissionable Isotope Mass Standards (FIMS).

(4) Quality assurance measurements of tantalum impurity in niobium were performed for several commercial and government laboratories using the thermal neutron irradiation facility at the reactor. The $^{92}Nb(n,n')^{92m}Nb$ reaction for fast-neutron dosimetry results in an x-ray emitting state with a 16-year half-life. If significant quantities (>20 ppm) of tantalum are generated in a neutron field with an appreciable slow neutron component, the tantalum becomes radioactive and decays with emission of the same energy x-ray as the ^{92m}Nb.

(5) An executive summary document is being prepared for the Nuclear Regulatory Commission which will delineate the accomplishments of a multi-laboratory program to improve surveillance dosimetry for reactor pressure vessels. NBS participation in the development of this document has become more prominent this year. A member of the group, in fact, was singled out by the funding agency and an executive committee of laboratory project managers to prepare a critical review of the 8-year old Reactor Pressure Vessel Irradiation Surveillance Improvement Program. The review was presented at an international gathering of power reactor safety experts.

Neutron Source Strength Calibration Facility (E. D. McGarry & E. Boswell)

NBS provides routine calibration of neutron source emission rates. Source strengths of 1.5×10^5 to 5×10^9 n/s are calibrated against a radium-beryllium photoneutron standard source, NBS-I, to an accuracy of about 1.2 percent by the manganeous sulfate bath technique.

(1) Within the last 12 months the NBS $MnSO_4$ Bath calibration facility has undergone extensive upgrading of radiation shielding, of source handling procedures, and of automated data processing. A new shield wall reduces personnel exposures by a factor of at least 100 incurred while loading and unloading sources into the $MnSO_4$ bath. Improvements include a slave manipulator for remote-source handling behind a water filled plexiglass window installed in a floor-to-ceiling shield wall. In addition, a programmable robot arm allows automated source-to-bath insertion and removal. Automated data processing includes micro-computer data collection and data reduction programs. Within the last 18 months a DEC PRO-350, with a 33 megabyte hard storage disk, has been successfully interfaced with $MnSO_4$ Bath electronics. Recalibrations of the Bath after the upgrading effort showed no change to within 0.4 percent.

(2) NBS has completed participation in an international comparison of neutron source strength determination methods. The NBS result for a source of nominally 2×10^7 n/s emission rate was reported with an accuracy of ±0.9 percent which was within 0.5 percent of the best "world average". Results from 13 laboratories were evaluated and reported by E. J. Axton, of the National Physics Laboratory, Teddington, England. The source involved now resides at NBS.

(3) Routine source strength calibration services are now back in operation. As of 1 August 1986, three sources have been calibrated for outside users. No outside-user backlog now exists; however, about six NBS sources await recalibration and four outside requests for neutron source calibrations work have been received.

An important in-house source calibration involves the ^{252}Cf Spontaneous Fission Neutron Source, NS-100, which played a major role in the determination of the ^{252}Cf fission-spectrum-averaged fission cross section of ^{235}U. About one-half of the uncertainty in that measurement is associated with the source strength of NS-100.

(4) An unusual source-strength calibration has been carried out for the University of Arkansas to assist them in establishing a regional personnel-dosimetry calibration laboratory and to make possible a measurement of the fission-spectrum-averaged cross section for the $^{92}Nb(n,n')^{92m}Nb$ reaction. For the latter measurement, a 32-mg ^{252}Cf source, one of the largest in the country (7.5×10^{10} n/s) was employed. This source cannot be handled or calibrated at the NBS $MnSO_4$ facility because of its intensity. An alternative two-step calibration was carried out as follows: 1) A second, 5×10^9 n/s source was procured with encapsulation (and therefore scattering and absorption) identical to the 32-mg source. This source was calibrated in the NBS $MnSO_4$ bath. 2) A direct on-site intercomparison of the 5×10^9 and the 7.5×10^{10} sources was accomplished at Arkansas with NBS fission chambers, equipment and personnel.

(5) Source strength calibration documentation, now required by NBS for all calibration and test services, has been drafted and submitted to the Laboratory for review and acceptance.

<u>Integral Neutron Cross Section Measurements</u> (G. Lamaze, D. Gilliam, J. Grundl, & E. D. McGarry) .

(1) The Department of Energy (DOE) is sponsoring a multi-laboratory effort to measure fission-spectrum-averaged cross sections of a relatively new reaction of interest for high fluence ($>10^{16}$ n/cm^2) neutron dosimetry. The reaction is $^{92}Nb(n,n')^{92m}Nb$ with a 16-year half-life. Many laboratories are involved because high fluence, standard-neutron-field irradiations are required and because the 92^mNb is an x-ray emitter which complicates the activity determination. NBS has completed a 30-day, 10^{17} n/cm^2 irradiation in the Cavity Fission Source for this project. The NBS Radioactivity Section will participate in the x-ray activity determinations together with the INEL Laboratory in Idaho, the University of Arkansas, and Harwell Laboratory in England. The 30-day irradiation in the NBS Cavity Fission Source, an essential component of the measurement, was six times longer than any previously performed with this source. A notable goal of the irradiation was successfully achieved: The ^{235}U fission disks were handled with minimal personnel radiation exposure.

(2) Our productive and pleasant collaboration with the University of Virginia Department of Nuclear Engineering and Engineering Physics is continuing. Professor Tom Williamson is presently analyzing data taken at

NBS during his sabbatical year. A paper on the measurement of photofission cross sections in the NBS neutron driven gamma ray field will be presented at the 6th ASTM-Euratom Symposium on Reactor Dosimetry. Photofission cross sections of ^{237}Np, ^{235}U, ^{238}U, and ^{232}Th were measured in both iron and cadmium capture gamma ray fields. These cross sections are important for correcting the neutron response of fission dosimeters used in all areas of materials performance assessment under stress of radiation. Professor Williamson and his students have also continued their analysis of data on the $^{93}Nb(n,n')$ spectrum-averaged cross section for ^{235}U fission neutrons. Niobium foil materials were irradiated in the Cavity Fission Source of the NBS Reactor in exposures of six and four days duration. The activity of each foil is measured by comparing the number of counts with the counts from NBS SRM 4267-8, a ^{93m}Nb activity standard. Preliminary results indicate an overall 3 percent uncertainty. Final results will be presented at the 6th ASTM-Euratom Symposium on Reactor Dosimetry.

(3) Integral tests of 10-100 keV-range neutron activation cross sections for Au, In, and Cu have been begun at the Intermediate Energy Standard Neutron Field (ISNF) facility at the reactor thermal column. In these tests, the neutron fluence rate is determined by a ^{239}Pu fission chamber monitor. Subsidiary measurements are being made to check for suspected problems of epi-thermal neutron leakage through the penetration for the monitor chamber stem. The neutron field near the penetration has been mapped by exposing of activation foils in the region of the penetration and comparing the results with foils activated in the ISNF with the penetration closed.

(4) The spectrum integrated helium generation cross section for ^{10}B in the NBS Intermediate-Energy Standard Neutron Field (ISNF) was measured by the HAFM technique some time ago and found to be discrepant with prediction by a surprising 10 percent. A paper was presented last year which investigated this discrepancy and others related to it. Since then some preparations have been made to make an independent measurement of this cross section in ISNF with the NBS double fission chamber. Such an active measurement in the high-intensity gamma fields within the NBS reactor thermal column poses severe experimental problems. The reaction products (^{7}Li recoil and alpha particle) which can be nicely resolved in a thermal beam outside of the thermal column cannot yet be adequately discerned in the ISNF arrangement inside of the thermal column. It may be necessary to use a Cf fission neutron source to drive the ISNF geometry in order to perform this measurement. There is good reason to carry out this measurement, if at all possible, because of the basic importance of the ^{10}B reaction as a standard against which many other cross sections are measured and the confidence which exists concerning the 1/v shape of the reaction cross section.

Benchmark Neutron Field Development and Application (G. Lamaze, E. D. McGarry, D. Gilliam, & J. Grundl)

(1) Several man months of effort were spent this year in documenting the calibration services offered in association with the NBS Fission Neutron Irradiation Facilities. Two documents, now in the NBS review process, will be published as NBS Internal Reports. They describe two services: Activation Foil Irradiations-Californium Fission Sources (44080C) and Activation Foil Irradiation-Cavity Fission Sources (44090C). The documents describe the characteristics, theory and operation of these benchmark neutron fields, including the traceability of their calibration to NBS-I. Available neutron fluences are given along with the uncertainty of relevant exposure parameters. The documents also detail operating procedure for performing irradiations in the hope of establishing some institutional memory.

(2) The Neutron Dosimetry Group is responsible for compiling a Compendium of benchmark neutron fields for reactor dosimetry. The compendium describes standard and reference neutron fields which are used to benchmark neutron dosimetry measurement methods. The latest edition of the Compendium distributed this year as a 130-page NBS internal report, describes three NBS Standard Neutron Fields and includes an evaluation of measured and calculated reaction cross sections for each of them.

(3) In parallel with the development of a compendium, and in support of the development of controlled-environment benchmark neutron fields by the Surveillance Dosimetry Improvement Program, a new ASTM standard for benchmark referencing is being drafted for ASTM Subcommittee E10.05. Work on the draft is about 70 percent complete and balloting is expected this fall.

(4) As part of a study to check the consistency of isotopic mass scales at a number of laboratories throughout the world, two ^{235}U deposits from the Khlopin Radium Institute (KRI) in Leningrad, USSR were made available through the assistance of the IAEA for measurements at NBS and Argonne National Laboratory (ANL). The study undertaken at the NBS consisted of two parts. One consisted in the measurement of the alpha-decay rates of the two ^{235}U samples (KRI VI and KRI-XV) with a low geometry counting spectrometry facility. This method gave results with an accuracy of ± 0.4 percent (1σ). The other consisted of the measurement of the total alpha disintegration rate of the samples employing a 2π alpha-counter by the Radioactivity Groups. This second measurement gave results with uncertainties in the range of 0.8 percent (1σ). The results by the two separate methods at NBS, results from low geometry alpha counting at ANL, and the KRI values all agree to within their stated error limits. This effort should contribute to the long-sought objective of 1 percent accuracies for the ^{235}U fission cross section. Results will be reported at the ANS Winter Meeting in Washington.

(5) The Fission Neutron Irradiation Facilities have been used to benchmark neutron dose and energy distributions performed by NBS in the specimen exposure rooms at the Armed Forces Radiobiological Research Institute (AFRRI) Reactor. Both active detectors (^{235}U and ^{237}Np fission chambers) and passive detectors (S, Ni, In, Rh, and Fe activation detectors) are involved. Results of these measurements have been analyzed using the NBS codes DETAN and SPAD to determine neutron spectrum, fluence and kerma for different shield wall configurations in the AFRRI exposure room.

(6) The gamma counting facility of the Neutron Dosimetry Group was improved this year by the upgrading of the Digital Pro-350 computer to the model Pro-380. The faster processor of this model has greatly reduced the time needed to analyze gamma spectra. No other major changes were made in either software or hardware in this facility as it has now achieved the level of "routine" operation. One new operational feature is the routine weekly calibration of the primary detector to check that there has been no change in the efficiency of the detector. This assures that the traceability of the cavity fission neutron fluences to NBS-I is maintained. A backup detector and analysis system is now also in routine use for measuring very low activity samples.

(7) The NBS collection of Fissionable Isotope Mass Standards (FIMS) along with a variety of absolute fission chambers are maintained for fast neutron field characterization measurements. The FIMS collection comprises reference deposits and working deposits of eight different fissionable nuclides. The masses of the reference deposits are known to accuracies of ±0.4 percent to ±2.5 percent (with 68 percent confidence). The distinct energy thresholds for these various fission detectors permit broad-group energy analysis as well as total neutron fluence rate determinations. Activities in maintenance of the FIMS collection this year included calibration of new working deposits of ^{238}U and relocation of the alpha assay system in newly allocated laboratory space.

Smaller Projects

(1) Preliminary work in support of a proposed neutron life-time experiment has begun. The responsibility of the Neutron Dosimetry Group in the proposed experiment would be the determination of the average linear density of neutrons in the neutron beam, downstream from an electromagnetic proton trap. A detachable neutron detector would be absolutely calibrated in a series of subsidiary measurements employing both cold neutron beams and thermal neutron beams. The active neutron detector will consist of a thin ^{10}B deposit, viewed by four surface barrier detectors. A study of possible materials for the backing of the ^{10}B deposit has been made, and thin (0.38 mm) crystalline silicon wafers have been chosen as the backing material. These single-crystal backings will scatter thermal neutrons less than half as much as would the thinnest possible

Al backing (0.13 mm). Furthermore, these crystal wafers are extremely smooth, flat, and rigid, so that good solid angle reproducibility and stability can be maintained.

(2) Two members of the group have been very active in ASTM Committee E-10 on Nuclear Technology. Dale McGarry is the principal author of the new standard on Benchmark Referencing and is a member of the planning committee for the 6th ASTM-Euratom Symposium on Reactor Dosimetry, to be held in Jackson Hole, WY in 1987. George Lamaze is the Vice-Chairman and acting Secretary of subcommittee E10.05 on Nuclear Radiation Metrology and is the Secretary of the planning committee for the Jackson Hole Symposium.

(3) The National Atomic Museum in Albuquerque, NM has requested advice and consultation regarding the development of a comprehensive display of the realities of nuclear energy. The exhibit will center around highlights of history and the demonstration of operating devices related to that history. NBS participation is through membership on a Steering Committee made up of representatives from selected nuclear energy laboratories and the American Nuclear Society. Efforts at NBS will be directed mainly toward the preparation of display texts and oral presentations which can challenge viewers of varying interests and backgrounds.

(4) A continuing problem with gamma-ray fluence measurements in mixed neutron and gamma radiation environments is the neutron sensitivity of the gamma-ray sensor. This is particularly true of new types of thermoluminescent detector materials (TLD) such as BeO and $A\ell_2O_3$. In a program initiated by the SCK/CEN Laboratory, Mol, Belgium, the NBS along with the English Berkeley Laboratory are cooperating in a TLD neutron sensitivity experiment. Conventional ^{7}LiF TLDs and BeO and $A\ell_2O_3$ TLDs have been exposed to a bare ^{235}Cf source for three hours and their response compared to a 10-day exposure to the same source surrounded by a 14-cm thick lead sphere. With the lead, the gamma dose from a californium source is reduced by a factor of about 10 to something less than 5 percent. The irradiations have been completed and the TLD materials returned to England and Belgium for evaluation.

(5) NBS personnel traveled to ORNL to participate in an absolute power level determination of a special reactor core assembled for a nuclear nonproliferation study. The power level was determined from fission rate measurements made with a miniature, needlelike, sealed fission chamber which could be positioned down among the fuel plates of the core elements. The absolute mass of ^{235}U in the fission chamber was determined before hand at the NBS reactor thermal column by comparison of its fission rate to that of an NBS fission chamber with a deposit of known mass.

(6) Prototype fission-scintillation counters developed by Lawrence Livermore National Laboratory (LLNL) were calibrated in tests at the

reactor thermal column. The neutron sensitivity data provided by these tests was used by LLNL scientists to make crucial settings of the recording oscilloscopes prior to weapons tests at the Nevada site in March, 1985. These data are also being used in interpretation of the test results.

(7) An experimental ^{7}LiF gamma dosimeter has been supplied under contract to the Babcock & Wilcox company for test exposure in the Oconee II nuclear reactor plant. This depleted ^{7}LiF crystal is shielded by an enriched ^{6}Li-glass enclosure and sealed in a welded aluminum capsule. Calibration tests with NBS ^{60}Co gamma sources will be made for other crystals from the same batch, and neutron sensitivity tests will be carried out using the cavity fission source.

V. Radioactivity Group

Introduction

Development of new techniques and basic calibrations were emphasized this year, with quality-assurance programs and Standard Reference Material production and distribution retaining importance. Operators' manuals for the alpha-particle and gamma-ray calibration services were broadened to include introductory material sufficient to describe the procedures to the general public and prepared for publication. Data handling and analysis were enhanced, and a new low-level gamma-ray spectrometry system designed. Interactions with instrument manufacturers, power-plant radiochemistry personnel, and radiopharmaceutical manufacturers and users were extended. The following paragraphs provide further details about selected topics.

BIPM Intercomparison of ^{109}Cd Activity Measurements (C. F. Ballaux, B. M. Coursey, & D. D. Hoppes)

Measuring the activity (decays per second) of ^{109}Cd is complicated by the electron-capture decay to a 40-s 88-keV state that decays largely by internal conversion. However, the weak 88-keV gamma ray provides one of the few useful efficiency-calibration points in this energy region for gamma-ray spectrometry systems routinely used to measure mixtures of radionuclides. This combination of challenge and utility, plus some previous international calibration discrepancies, led to the distribution of a common solution to some 20 national and international standardizing laboratories under the sponsorship of the Mesure des Radionucléides section of the Comité Consultatif pour les Etalons de Mesure des Rayonnements Ionisants of the Bureau International des Poids et Mesures. Participants were invited to measure the emission rate of either the x and gamma rays (per unit solution mass), in addition to the activity concentration. The resultant value of the probability per decay for these photons could then be used to relate SRMs calibrated for activity or photon-emission rate.

Measurements were performed at NBS in March, 1986, with the assistance of a guest scientist from the Studiecentrum voor Kernenergie in Mol, Belgium. The experiments and their results are:

(1) The emission rate of conversion electrons from BIPM ^{109}Cd sources was measured with a liquid-scintillation counter, with the small correction for a gamma-ray contribution calculated from a literature value for the total-conversion coefficient and calculated values for the efficiency. The value was 5.721×10^6 $s^{-1}g^{-1}$ ± 0.49 percent.

(2) The emission rate of gamma rays was measured with a small-diameter-well NaI(Tl) spectrometer for which the efficiency was calculated and checked. The value was $(2.191 \pm 0.010) \times 10^5$ $s^{-1}g^{-1}$.

(3) The two above results were added to give an activity concentration of $(5.940 \pm 0.028) \times 10^6$ Bq g^{-1}. The ratio of the two results was used to give a total-conversion coefficient, α, of 26.11 ± 0.17. The feeding to ^{109m}Ag is nearly complete, so the gamma-ray probability per decay, P_γ, is simply $(1 + \alpha)^{-1}$, or 0.03689 ± 0.00024.

(4) An activity concentration for the ^{109}Cd was derived from comparison of gamma-ray rates with the beta-particle-emitting analog ^{109}Pd activity-calibrated with the liquid scintillator, using the total-conversion coefficient measured above to evaluate the ^{109m}Ag efficiency. The value was 6.006×10^6Bq g^{-1} ± 0.48 percent. A ^{109}Pd half life of 13.404 ± 0.008h was measured by following the decay for 11 half lives on a germanium gamma-ray-spectrometry system.

(5) The gamma-ray probability per decay for the ^{109}Pd solution was derived from the activity measured in (4) and a gamma-ray-emission rate measured with the NaI(Tℓ) well counter. $P_\gamma = 0.03648 \pm 0.00031$.

(6) A tentative measurement of the ^{109}Cd conversion-electron rate was made with a thin-film source pressed between two cooled Si(Li) detectors. The value was 5.729×10^6 $s^{-1}g^{-1}$ ± 1.1 percent.

<u>Large Area Source Calibration Technique</u> (J. M. R. Hutchinson)

The program to develop traceability of U.S. Air Force alpha-particle field measurements is virtually complete. Large area ^{238}Pu sources mounted on conducting backings have been examined for response as a function of vertical and horizontal position, aperture size and shape, etc.

The objective of providing a calibrated response for the Radiac Calibrator with an uncertainty less than ± 10 percent appears to be achievable. Some preliminary measurements to characterize the x-ray and low-energy-photon response of the calibrator have been initiated.

Experiments with Resonance Ionization Mass Spectrometry (J. M. R. Hutchinson & K. G. W. Inn)

NBS has collaborated with Atom Sciences, Incorporated and Colorado State University in developing a new technique called Sputter Initiated Resonance Ionization Mass Spectrometry (SIRIS) for ultrasensitive measurement of trace amounts of nuclides. Our particular interest is in the use of this technique for the measurement of radionuclides in soils, sediments, and other naturally occurring materials as a means of providing calibrations of radionuclide concentrations in the NBS natural matrix-standards. The technique will have many other applications in other areas such as industry and medicine.

Recently, we have sought to place this mass spectrometric technique on a sound basis for quantitation of materials. A major, in fact the major, source of uncertainty in many instances in measurements conducted using other mass spectrometric techniques is traced to isotope fractionation, especially when the isotope dilution technique is being applied for the calibration. For example, fractionation of molybdenum isotopes in the usual sputter-initiated mass spectrometry (SIMS) is approximately one percent per a.m.u. and 10 percent per a.m.u. in beryllium in conventional thermal ionization mass spectrometry. Special techniques, including calculated estimates containing significant uncertainties, are used to overcome these problems and are often not really satisfactory.

In SIMS, the fractionation is associated in the literature with the ionization process. Since SIRIS utilizes neutrals, there is hope that fractionation will not be a problem, since the ionization occurs by the totally different and controllable process of laser excitation. (Generally we try to saturate the transitions.) If this were the case, it would be a highly significant finding in the development of ultrasensitive technology.

The problem of molybdenum isotope fractionation in SIRIS from a metallic source has been under study by our group recently. A time-of-flight mass spectrometer replaced the magnetic one in SIRIS. A spectrum readout is shown in Fig. 1. The fractionation results are shown in Fig. 2. The even isotopes taken separately from the odd isotope data show no fractionation whereas the odds differ from the evens by about 15 percent. In all likelihood, this is associated with hyperfine splitting in the odd-A's. In the future, we will investigate the specific role hyperfine splitting plays in fractionation in SIRIS and attempt to develop techniques to avoid measurement uncertainties associated with this effect.

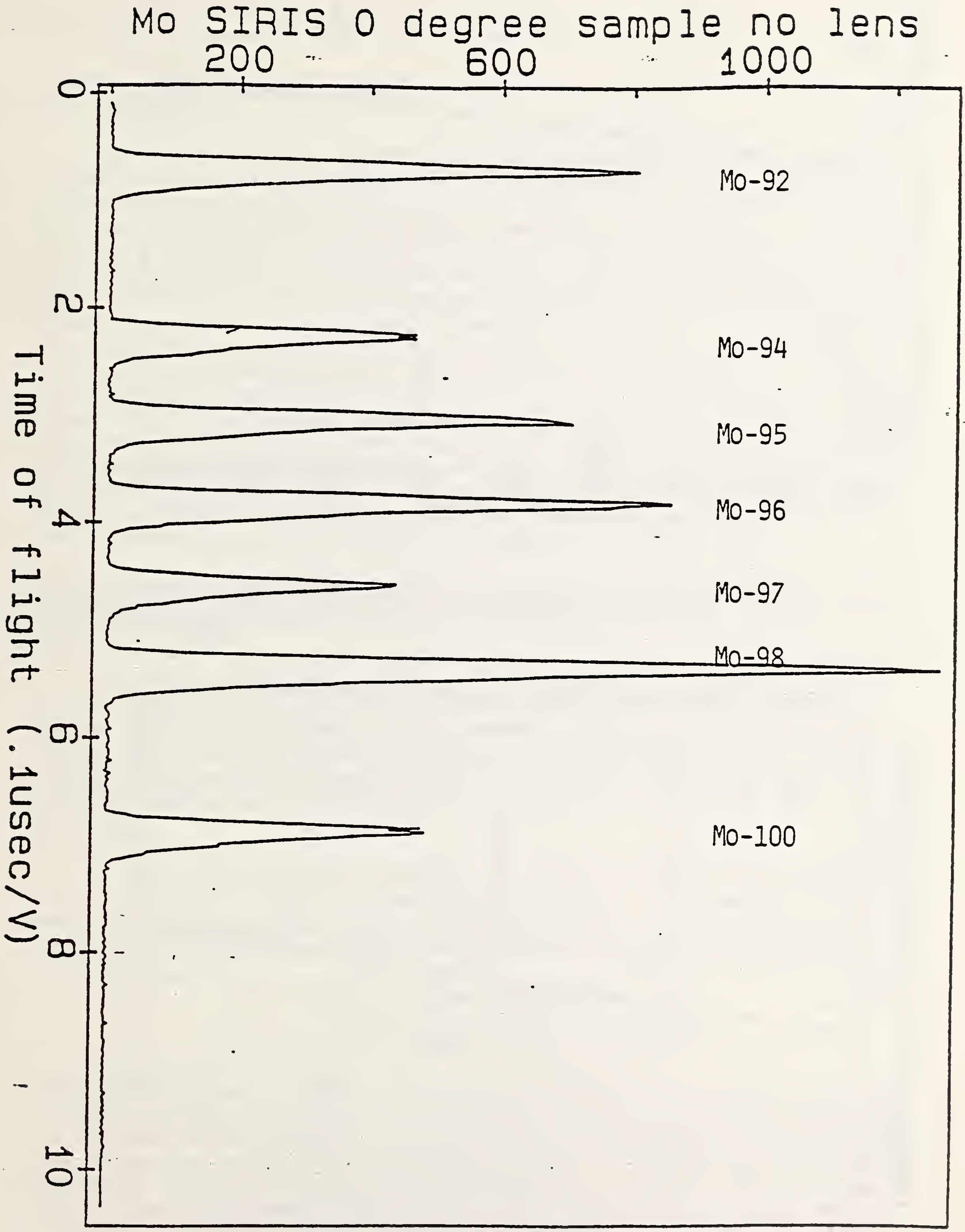
Mo SIRIS 0 degree sample no lens
200
600
1000
0
2
4
6
8
10
Time of flight (.1usec/V)
Mo-92
Mo-94
Mo-95
Mo-96
Mo-97
Mo-98
Mo-100

FIG. 1

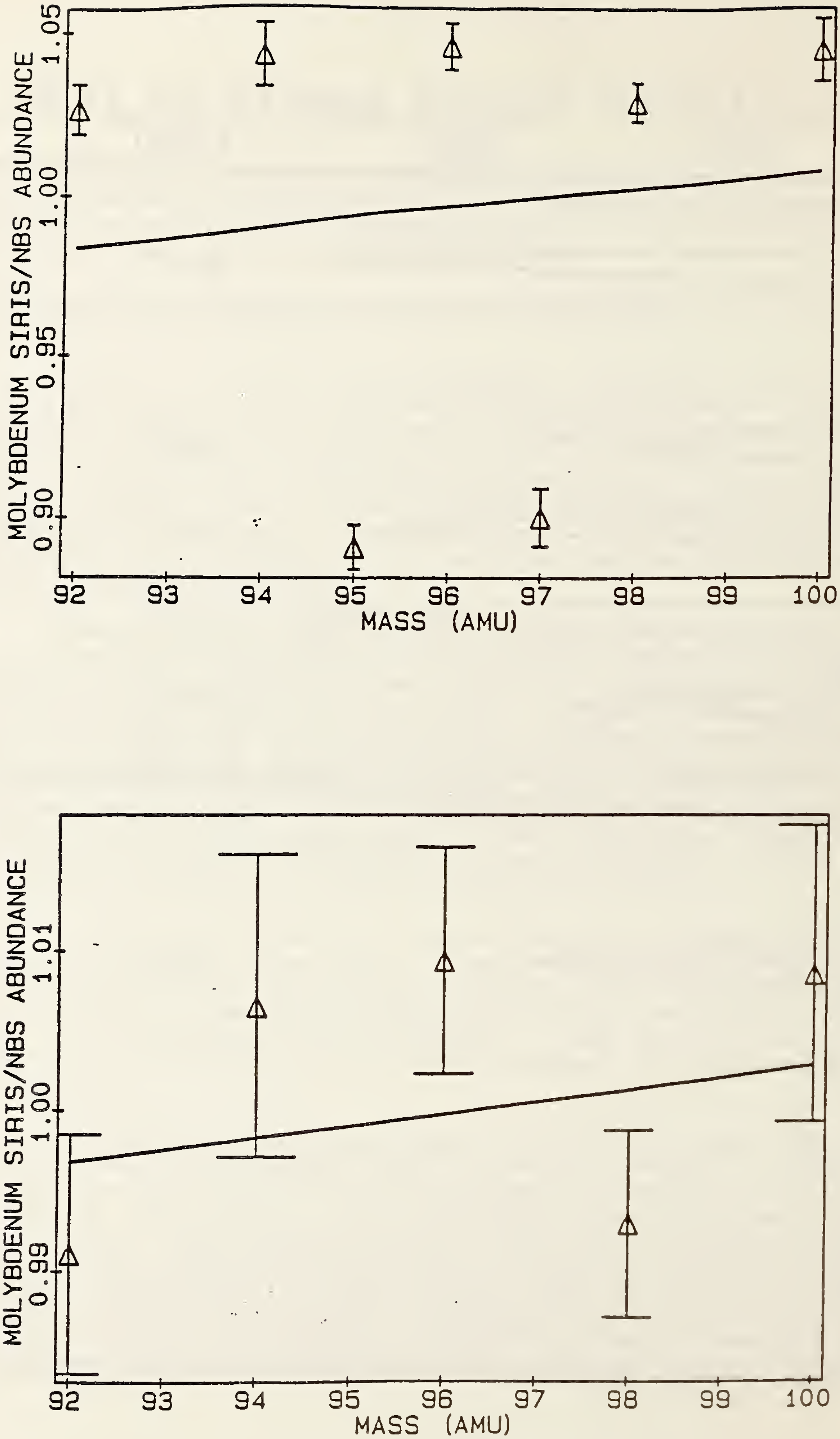
MOLYBDENUM SIRIS/NBS ABUNDANCE
1.05
1.00
0.95
0.90
92
93
94
95
96
97
98
99
100
MASS (AMU)
MOLYBDENUM SIRIS/NBS ABUNDANCE
1.01
1.00
0.99
92
93
94
95
96
97
98
99
100
MASS (AMU)

FIG. 2

^{10}Be-^{9}Be Isotopic Ratio Standard (K. G. W. Inn, J. M. R. Hutchinson, and B. M. Coursey)

The tandum accelerator mass spectrometry (TAMS) community has been engaged in ultra-sensitive isotopic ratio measurements of $^{10}Be/^{9}Be$ for significant geochronology studies. An isotopic ratio standard is being prepared in cooperation with Oak Ridge National Laboratory and TAMS users to bring consistency to the TAMS community. The master material was isotopically enriched for ^{10}Be and mass analyzed by secondary-ionization mass spectrometry at Oak Ridge National Laboratory. At NBS, the master material has been further characterized by liquid-scintillation measurements and will be mass analyzed by thermal-ionization mass spectrometry. All of this information on the master material will be used for a high precision half-life evaluation of ^{10}Be; to date, the half life of ^{10}Be is known only to ± 20 percent. The master material has been diluted with high-purity single-crystal ^{9}Be in sequential steps to a 2400 g solution containing 5 mg of Be/g solution, and a $^{10}Be/^{9}Be$ ratio of 3×10^{-11}. The dilution has been confirmed by liquid scintillation counting down to the second-to-the-last dilution (10^{-9}). The final dilution step will be confirmed through an interlaboratory comparison of TAMS users.

Distributions of Calibrated Samples by Commercial Pharmaceutical Laboratories in FDA-Organized Quality-Assurance Exercises (B. M. Coursey and J .M. Calhoun)

In order to assess the quality of measurements of radioactivity in nuclear medicine, the Center for Devices of the F.D.A. has organized quality assurance programs in which commercial laboratories select a fraction of their normal customers to receive a standardized sample in the normal container; for example, ^{99m}Tc in saline solution in an injection syringe. NBS personnel coordinate the calibration aspects of the program.

In the first exercise, completed this year, Syncor, Intl. distributed ^{99m}Tc in syringes. Responses were received from 172 customers. The customers' values, obtained primarily with commercial dose calibrators, were compared with the known values from the Syncor calibration laboratory:

141 values within ± 5%
164 values within ± 10%
169 values within ± 20%

The US Pharmacopaeia requires ± 10 percent accuracy on injected doses.

In the second exercise, initiated this year, Dupont/NEN Products distributed the heart-imaging agent $^{201}T\ell$ in their usual serum vials to 62 customers. Earlier this year Dupont calibrated their ionization chambers in the serum-vial geometry with NBS standard solutions. In July NBS personnel visited the Dupont laboratory to review the calibration records and the protocol for distribution. Eight vials were sent to NBS for measurements with commercial dose calibrators and Radioactivity Group ionization chambers. The average for the Dupont activity for the 8 vials was 0.5% higher than NBS (the worst deviation was + 0.9%). As with the earlier Syncor exercise, Dupont's customers' results will be forwarded to the FDA for evaluation, with individual identities not revealed.

U.S./Spain Joint Project for the Development of Liquid-Scintillation Techniques for the Standardization of Radionuclides (B. M. Coursey, A. Grau Malonda*, E. Garcia-Toraño*, J. M. Los Arcos*, M. T. Martin-Casallo*)

The NBS and the JEN (Madrid) are in the third year of a 5-year joint project, sponsored by the US/Spain Joint Committee for Scientific and Technological Cooperation to improve the accuracy of liquid-scintillation techniques. The first year dealt with the standardization of pure-beta-emitting radionuclides and the second year with electron-capture (EC) decay radionuclides. Two extensive computer codes, EFFY2 for beta emitters and VIAS for EC-decay nuclides, have been implemented on the NBS CYBER 855 and the JEN UNIVAC. Separate Monte Carlo programs have been written to compute wall distortions for high-energy electrons, and interaction probabilities for x and gamma rays. The computer work in the third year will entail incorporating these routines into programs EFFY2 and VIAS, which will allow us to compute efficiencies for β-γ emitters (^{59}Fe, ^{203}Hg) and EC-decay nuclides (^{111}In, ^{201}Tℓ).

The experimental liquid-scintillation measurements associated with this project are closely coordinated with the computations to allow us to verify the usefulness of the programs. Measurements on beta emitters during this year include ^{10}Be, ^{32}P, ^{33}P, ^{89}Sr, ^{109}Pd and ^{114}In. A publication describing earlier results for ^{63}Ni and ^{241}Pu is in preparation. A paper on ^{14}C appeared this year. A publication has also been prepared describing the standardization of ^{99m}Tc, which decays by an isomeric transition.

Techniques are also being developed for the measurement of radionuclide mixtures and impurities:

radiostrontium	^{82}Sr, ^{85}Sr, ^{89}Sr, ^{90}Y
radiophosphorus	^{32}P, ^{33}P
radioindium	^{111}In, ^{114m}In

The experimental phase of these studies is complete but further refinements to the programs will be necessary before we can match the computed and observed spectra.

*Guest scientists from Junta de Energia Nuclear, Madrid

Activity Measurements and Decay-Scheme Studies of ^{82}Rb. (D. D. Hoppes, B. M. Coursey, and F. J. Schima)

Positron-emission tomography for medical imaging makes use of short-lived radionuclides in order to minimize radiation dose to the patient. A system for delivering positron-emitting 76-s ^{82}Rb from a generator loaded with 25-d ^{82}Sr was developed in the early 1980s, and radiopharmaceutical companies in the Atomic Industrial Forum cooperative quality-control program with NBS asked that basic activity calibrations be developed for these radionuclides.

The ^{82}Sr decays by pure electron capture, which rules out the usual schemes using cascade radiations to effect a direct calibration. Measurement of the ^{82}Sr - ^{82}Rb equilibrium mixture in the past had used gamma-ray spectrometry of the 511-keV photons from the annihilation of positrons with a maximum energy over 3 Mev. The fraction of electron capture relative to positron emission is calculated to vary from 0.03 for the dominant ground state branch to 700 for high excited states, hence a calibration based on positron measurement requires a knowledge of the branching to excited states. A further complication to annihilation-radiation measurements of the equilibrium mixture is the presence of large, often dominant, amounts of a ^{85}Sr impurity with a 514-keV gamma ray. The short half life of separated ^{82}Rb complicates measurements of that radionuclide, and make transference of NBS calibrations to simple instruments such as dose calibrators in nuclear-medicine clinics impossible.

However, an isolated 776-keV gamma ray can be measured readily on spectrometry systems with efficiencies calibrated as a function of energy, if its gamma-ray probability per decay can be established. This was a primary goal of measurements performed at NBS in 1983 on both equilibrium mixtures and separated ^{82}Rb, with the assistance of guest scientist Yang Dongliang of the Peoples Republic of China.

In that series of measurements, liquid-scintillation counting of the positrons was also used, with an apparent discrepancy of about +5 percent with respect to the annihilation-radiation measurements. Measurements of the relative probability of gamma rays from ^{82}Rb established the decay branchings to higher levels, and the change in the emission rate of the 776-keV gamma ray from the equilibrium mixture with time yielded a half life of 25.36 ± 0.03 days.

Although preliminary results from the National Physical Laboratory in the UK seemed to support the annihilation-radiation results, we felt that further measurements were required in order to understand our earlier discrepancy. In late 1985, relatively pure ^{82}Sr-^{82}Rb was obtained and measured by both liquid-scintillation counting and germanium spectrometry of the 511-keV photons, with additional geometries used to probe the substantial correction for annihilation in flight with the latter method.

The earlier discrepancy was substantiated, which suggests that quantitative measurements of high-energy positrons may need further investigation. However, use of either resultant value for the probability per decay for the 776-keV gamma ray, or a simple average, will lead to improved routine analysis of radiopharmaceuticals. The two gamma-ray-probability values are 0.152 ± 0.003 (positron rate from annihilation radiation) and 0.145 ± 0.002 (liquid-scintillation counting of the positrons), where the uncertainties are root-mean-square combinations of all suspected components estimated as approximations to one standard deviation.

Distribution of Radioactivity Standard Reference Materials (SRMs) and Measurement Services

The following table sumarizes explicit interactions which propagated basic NBS activity calibrations between August 1, 1985 and July 31, 1986.

Total Radioactivity SRMs distributed	816
SRMs under the AIF program for nuclear medicine	217
Scheduled Calibrations	35
Special Measurements	70
Traceability exercises including EPA, FDA, NRC, and commercial firms	128

The traceability exercises carried out with the regulatory agencies, radiopharmaceutical manufacturers, and suppliers of commercial reference materials test the ability of a laboratory to supply an activity value for a sample of a radionuclide before the NBS calibration is known. The exercises do not, except in special cases or by inference, test or investigate the general quality-control procedures within the laboratory, which would be a much more ambitious undertaking.

VI. X-Ray Physics Group

Radiology and Radiography Standards and Measurement Methods (J. H. Sparrow)

The X-Ray Physics Group has performed evaluations of DOD high energy radiological inspection systems.

At the request of the Navy Department, this program carries out the following tasks:

1) Measure and calibrate every 12 to 18 months the x-ray outputs of approximately ten 16 MeV Linear Accelerators used by DOD for radiological inspection systems.

2) Propose radiological procedures to determine image quality achieved during production and refitting inspections of missiles; approximately every 6 to 12 months, perform an on-site audit of the radiological image quality achieved at the various DOD facilities and at the various DOD product manufacturers; participate in the development of radiological penetrameters which are used as image quality indicators; and participate in new design of a test specimen used to evaluate both image quality and system performance for high energy CT radiological inspection systems.

3) Assist in the integration of old and new radiological methods. (film, real-time, and tomography), to assure that adequate image quality is achieved during routine inspections.

4) Propose radiographic equipment which can be used at the DOD facilities and DOD vendors to monitor x-ray beam energy fluence and beam positions.

Dental Fluoroscopy and Tomography (J. H. Sparrow & C. E. Dick)

In cooperation with the National Institute of Dental Research and the Army Institute of Dental Research, the X-Ray Physics Group is developing different types of real-time intra-oral x-ray imaging sensors which will be used in the development of a digital dental tomographic system. One type of x-ray sensor that has been developed and tested consists of an x-ray scintillator and a coherent fiber optic bundle which transmits the dental image out of the mouth to a video camera system. A second type of x-ray sensor under development consists of a semiconductor wafer with a pixel array that will have a spatial resolution of 5 line pairs per mm. The video output signals from these sensors will have specialized electronic equipment and software which are presently under development. With this equipment, the imaging system will have the capability of image processing, storage and transmission. In addition, special x-ray sources are under development which will permit the imaging system to produce dental tomographic images with x-ray exposure times less than 1 second.

Digital Energy Subtraction Imaging for Biomaterials (C. E. Dick)

In many medical x-ray imaging tasks, the specific structures and pathologies to be examined are cluttered with interfering images of surrounding structures and exhibit insufficient contrast relative to the surroundings to be successfully imaged with conventional techniques. To overcome these difficulties, a program is underway to utilize the differential absorption of different energy photons to provide a difference signal between the object of interest and the surrounding medium. In general, this requires photon beams with larger energy difference than previously employed. In addition, other aspects of digital subtraction techniques are being pursued including the maximization of the image difference signal using contrast media and image processing techniques.

In order to provide photon beams with large average energy differences, a method has been developed for generating quasi- monoenergetic beams with sufficient intensities for imaging systems. These beams are generated by selective filtration of typical diagnostic x-ray spectra. In addition, a computer algorithm has been developed which will predict with reasonable accuracy the effects of filters on diagnostic spectra and thus ameliorates the amount of experimental data that must be taken.

To record the images, a digital imaging system consisting of an image intensifier, a tv camera, and a digital image processing system has been assembled. Preliminary testing of this system indicated that the resolution of the original image intensifier-camera system was insufficient for the imaging tasks being considered and the image processing system lacked the necessary flexibility to facilitate digital enhancement. In the past year this system has been considerably enhanced by replacing the image intensifier with a new imager-camera system which has increased sensitivity and variable magnification. At the present time, a new image processing system is under development based on the use of a personal computer as a host for a dedicated pipeline processor and image storage system. As in the original system, archival storage will be provided by the use of Winchester type hard disk systems.

Finally, a collaborative program has been completed with an industrial guest worker to examine the properties of various compounds to be used as image contrast media. This program examined the physical properties of halogenated, rare earth, and heavy metal compounds to determine a systematic basis for their use in such methodologies as digital subtration angiography (DSA).

<u>4-MeV Van de Graaff Accelerator</u> (C. E. Dick)

The 4-MeV Van de Graaff accelerator is now in use as a pulsed electron source for studies in pulsed radiolysis. Electron beam pulses with a width of 0.5 microsecond and a pulse current of up to 0.5 Ampere are being utilized in preliminary experiments on the production of free radicals in chemical systems. Currently, construction is underway on quadrupole focussing elements to permit the production of line shaped beams to maximize the amount of electron beam current along the optical analysis axis. Additionally, a toroidal beam monitor has been developed to measure the pulsed beam current without interference with the electron beam.

HIGH-DOSE RADIATION CALIBRATION

Services Documentation (J. C. Humphreys)

Documentation has been developed that describes the calibration services available at NBS for the standardization of high absorbed dose measurements of ionizing radiation (pertinent to photons and electrons, but not neutrons or heavy ions). Detailed descriptions are given of the gamma-ray irradiation facilities available, the dosimetry procedures and dosimetry systems employed, and uncertainty assessment of all facets of the service. Internal quality control procedures and techniques relevant to these calibration services are given.

Industrial Radiology (R. C. Placious)

One of the many needs in industrial radiology that we have responded to is the development of standards related to quantification of performance evaluation image forming radiographic/radiologic systems. For example, we are now involved in developing both the procedures and the materials for measuring image quality at very low (30 kV) and very high (4-25 MeV) energies. We produced a draft document for the high energy image quality measurement which is based on nearly 500 individual tests throughout the country. The first revision of this has now been submitted for peer review . The low energy effort is not yet at this stage of development and we are presently working on the design of the test device and the prescription for beam quality. These two energy regions are of great industrial interest. Much inspection of composite materials is done at low energies while walled metal containers (vessels, casks, armor plate) need to be inspected with high energy radiation sources; (see Radiologic Inspection of Thick Walled Shipping Containers elsewhere in this report). We have received requests to assume a key role in the development of other radiologic standards. These include:

1. Voltage Calibration of X-Ray Sources (for users)
2. Microfocus Radiography and Sources
3. Digital/Real Time Performance Standards

Radiology for Thick Walled Shipping Casks (R. C. Placious)

Sandia Laboratories has asked NBS to prepare a report on the flaw detection limits in the nondestructive inspection for special nuclear materials. The radiographic/radiologic part of this work was prepared in the X-Ray Physics Group of the Ionizing Radiation Division. In addition to providing flaw detection sensitivity, the report recommended the best procedure to follow for a given type of flaw.

The impetus for this relates to requests that the United States switch to monolithic cask structures for both economic and safety reasons. Such structures are permitted in Europe, but not yet in the United States (by NRC).

VII. Dosimetry Group

Use of ionizing radiation is becoming ever more widespread in modern society. The exposure of humans can be purposive (medical) or incidental (occupational), but both require close control to ensure that the radiation is efficacious in the one case, and harmless in the other. Such control can only be achieved with reliable measurement. With the increased use and the improved knowledge of radiation effects, the need for more accurate measurement is constantly increasing. The measurement of ionizing radiation for the purpose of controlling a radiation effect falls in the field of radiation dosimetry. The Dosimetry Group has the responsibility for providing an up-to-date basis for reliable measurement in dosimetry of ionizing radiation, principally in medicine and radiation protection. This program involves: (1) establishment and maintenance of the national primary dosimetry standards; (2) dissemination of the units established by those standards by means of calibration services and measurement quality assurance programs; (3) research in measurement technology as necessary for any part of the program; and (4) participation in the relevant national and international activities of the community of radiation users.

X-ray and Gamma-ray Calibration and Measurement Assurance Services
(J. T. Weaver, P. J. Lamperti, & E. L. Bright)

Calibration services for x-ray and gamma-ray measuring instruments continues at approximately the same rate as the previous year.

The 100-kV computer program used on the DEC 1123 minicomputer has been modified with more overlays, which reduces memory requirements so that a later version of the operating system can be used; all data is now stored on a hard disc. These changes allow the 100-kV and the 300-kV calibration programs to store data on the same file. Use of a hard disc and the NBS net allows faster and more reliable data transfer to the host Cyber 855.

Measurement assurance tests have been carried out with the five AAPM therapy-level accredited calibration laboratories and the Center for Devices and Radiological Health. A small but significant error was uncovered in one of the AAPM laboratories by this test. In these measurement assurance tests, the test equipment is shipped around to all the laboratories before return to NBS, using the check methods devised for the particular equipment being used. Traceability to NBS is maintained by such a measurement test, without the necessity of returning the local standard to NBS, unless the test shows it to be necessary.

The Navy thermoluminescence dosimetry (TLD) measurement assurance program, sponsored by the Space and Naval Warfare Systems Command, continues. NBS receives boxes of 15 TLDs from the Naval Surface Weapons Center and irradiates 12 of them to known exposures with ^{137}Cs gamma rays. The boxes are dispatched to designated Naval units for readout, the results of which are returned to NBS for data reduction and comparison to NBS exposures. The results are sent to the sponsoring agency, who schedules a retest or recalibration for any TLD readout instruments that indicate exposures that differ from the NBS exposure by more than ± 13%. About 275 such boxes, containing 3300 exposed dosimeters, were dispatched during FY86. Also a 120-Ci ^{137}Cs source was calibrated for the Navy on three ranges.

Fifteen brachytherapy sources (small-size sources used in medicine and industry) were calibrated. In order to do this, the data on the NBS ^{137}Cs sources was reevaluated and new values assigned. An uncertainty in the brachytherapy calibration, relating to the influence of the source size and shape on the scattered radiation, was resolved by comparing measurements in the concrete brachytherapy calibration trough with calibrations made under free-air conditions.

The documentation of the NBS calibration procedures for x-ray and gamma-ray measuring instruments has been completed. This extensive document (> 120 pages), covering 20 years of development of exposure standards and measurement techniques, has been accepted by the appropriate review authorities.

A guest scientist from China has been trained in exposure calibration methods, and a graduate student in the Radiation Sciences program at Georgetown University has served a short internship on dosimetry calibration methods.

The Dosimetry Group provided assistance to the Federal Emergency Management Agency (FEMA) for an energy-dependence study of prototype personnel dosimeters, and also to the Department of the Army, Redstone Arsenal, for special high exposure for testing of prototype TLD dosimeters. The Dosimetry Group was called upon on very short notice to provide consultation and assistance to E.G.& G., Idaho Falls, concerning a high-priority personnel protection measurement problem, which involved selection of instruments, calibration beam qualities, and provision of calibrations for various instruments under a variety of conditions.

High-Energy Electron and Photon Measurement-Assurance Services (C. G. Soares)

Users of medical linear accelerators for cancer teletherapy need assurance that their machines are delivering the required radiation dosage. To meet this need, NBS offers a measurement assurance service that involves mailing to the users passive dosimeters to be irradiated in a prescribed geometry and returned to NBS for evaluation. For this service, ferrous-ferric (Fricke) dosimeters are used at present.

There were four mailings of Fricke dosimeters in FY86, involving 62 sets of participants. Two batches of dosimeters were prepared. In principal, each dosimeter can be used as many times as it takes to accumulate 200 to 300 Gy (20 to 30 krad). In order to conserve time, and thus cost to the participants, the tests are administered simultaneously to as many participants as the batch size permits. To handle the increase in volume that the service has experienced in the last few years, 60 new cells have been purchased, which, when successfully worked into the system, will allow an increase in the number of cells per mailing, and possibly a decrease in the number of mailings per year. It is planned to augment this chemical dosimetry service with a TLD service, if technical problems connected with the required extensive automation can be solved.

Documentation on the NBS procedures for the Fricke measurement assurance service has been completed and accepted by the appropriate review authorities.

Standard Monoenergetic Electron Beams (C. G. Soares)

NBS has been requested by the radiation protection community to establish standards for and assist in the development of methods of measuring the beta-particle radiation fields that are found in nuclear power installations. Beta-particle detection instrumentation is currently being calibrated using only broad-spectrum radionuclide sources. In order to determine instrument response as a function of energy in detail, NBS has developed a set of accelerator-produced nearly monoenergetic electron beams. Measurements made of response functions of various instruments has indicated that the monitoring system that has been employed restricts the reproducibility of such measurements to an unacceptably high level (10-15 percent). This is caused by changes in the field shape between the time when the off-axis monitor is calibrated and when the instrument response is measured. To try to overcome this difficulty, a new monitoring and control system was designed and constructed during FY86. This system consists of four off-axis monitors that feed back to beam steerers that control the field shape dynamically. While construction of the system hardware is complete, software is still being fine-tuned; it is not yet known if the system will be successful at increasing measurement reproducibility.

Beta-particle Source Calibration and Associated Measurement Assurance Services (J. S. Pruitt)

NBS provides the only calibration available in the United States for ophthalmic beta-particle applicators, which are sources of $^{90}Sr+^{90}Y$ encapsulated in stainless steel so that only the energetic beta particles of ^{90}Y are emitted. These applicators are used for treating various medical conditions on the anterior surface of the eye. In response to requests from the radiation-protection community, NBS is establishing a calibration facility for broad-beam beta-particle sources of $^{90}Sr+^{90}Y$, ^{147}Pm, and ^{204}Tl.

The NBS extrapolation chamber has been used to calibrate four ophthalmic applicators for absorbed dose to water at the applicator surface. In conjunction with these calibrations, quality assurance techniques have been devised and implemented using the NBS ophthalmic applicator (SN 0258) in a reproducible position. The SN 0258 current is reproducible to well within 1 percent, a small fraction of the stated uncertainty of calibrations which is ±15 percent.

The two PTW extrapolation chambers have been used to measure a complete depth-dose curve for ^{147}Pm in polyethylene terephthalate. One of these chambers still has the 2.61 mg/cm^2 graphite-coated entrance window with which it was originally supplied, but the other has been changed to a 0.7 mg/cm^2 aluminized polyethylene terephthalate window in order to reduce the extrapolation necessary to obtain calibrations at zero absorbed depth. The dependence on source distance has been carefully measured for the ^{147}Pm source in an effort to evaluate the correction needed for attenuation in the extrapolation chamber air gap.

A trip was made to Battelle-Pacific Northwest Laboratory to inspect their facilities for making beta-particle calibration measurements and to compare depth-dose curves measured at BPNL and NBS for a special $^{90}Sr+^{90}Y$ source encapsulated with a titanium window. The results of this comparison are incomplete at the time of writing because the BPNL experimental setup is still under development.

Perturbation measurements as a function of source distance have been started with the ^{147}Pm source. These measurements lead to a correction for scatter from the side walls of the PTW extrapolation chamber. This correction was measured by the PTB for the standard distance of 200 mm only.

Documentation on the NBS procedures for calibration of ophthalmic applicators has been completed and accepted by the appropriate review authorities.

Absorbed-dose Calorimetry (S. R. Domen)

Medical and industrial applications of ionizing radiation are quantified in terms of the physical quantity absorbed dose, which is the energy absorbed per unit mass in the material of interest. The calorimeter, which measures absorbed energy in terms of a temperature rise, is the logical standard of absorbed dose. NBS has developed a series of calorimeters, as part of a program to provide reliable national measurement standards for absorbed dose. The two most recent are a graphite-in-water calorimeter for radiation at medical-level intensities, and a polystyrene calorimeter for radiation at industrial intensities.

The graphite-in-water calorimeter was designed to allow determination of water absorbed dose, while avoiding the uncertainties associated with the radiation chemistry of laboratory water. Measurement with that calorimeter have shown good agreement with earlier measurements using other calorimeters. A redetermination of the NBS standard of absorbed dose is in progress, involving three kinds of NBS calorimeters and suitable ionization chambers.

The medical-level NBS graphite calorimeters require evacuation to obtain adequate thermal isolation of the calorimeter core. The polystyrene calorimeter was designed for use at atmospheric pressure in high-level radiation fields. It measures the temperature rise in a polystyrene cylinder of variable radius, and from this it is possible to calculate the absorbed dose to polystyrene and other low-atomic-number materials. It has been used to determine the absorbed dose rate in the NBS ^{60}Co pool source, by putting the calorimeter in a stainless- steel cylinder that is a replica of the cylinder used to irradiate materials being studied. The measured dose rate was in agreement within 1 percent with that measured earlier using a relatively complicated evacuated graphite calorimeter.

Dosimetry of High-Energy Photon and Electron Beams (L. J. Goodman, C. G. Soares, & R. Loevinger)

It is proposed to use the electron beam of the NBS racetrack microtron to produce collimated beams of high-energy photons and electrons, which will simulate those used clinically for cancer therapy. These beams will be used in a research project to test the adequacy of current protocols to provide accurate dosimetry measurements. The tests consist of measurements of photon fields and electron fields to compare dosimetry with ionization chambers calibrated according to prescribed protocols with dosimetry performed with an absorbed-dose calorimeter.

This work will use a separate beam line to transport the electron beam to a transmission window from which the beam will enter a target and collimator assembly. Accelerator beam parameters will range from about 180 μA at 5 MeV to about 1 μA at 35 MeV. Calculations indicate that it may not be necessary to shield other instrumentation in the room from this experiment. When the collimated beams are operational, the need for shielding will be reevaluated and shielding will be installed if necessary. All apparatus, except for the beam line to the target, has been designed, cost estimates have been obtained, and funding is being sought.

Development of Dosimetry Standards for Neutron Therapy (L. J. Goodman, D. M. Gilliam, S. R. Domen, J. J. Coyne, & R. S. Caswell)

The aim of this work is to improve the accuracy and consistency of measurements of absorbed dose for neutron radiation therapy by providing national dosimetry standards and improved data on neutron interactions with tissue and tissue-equivalent materials. Neutron radiation therapy is being clinically tested at several centers in the United States, and also other centers worldwide. The U. S. dosimetry standards base must be accurate and consistent with the international standards system in order to provide good physical dosimetry to ensure the success of the neutron therapy trials, and to facilitate the exchange of information between institutions. The role of NBS in providing neutron dosimetry standards will be similar to the long-established role for photon radiation standards.

The technical approach is to develop a tissue-equivalent (TE) ionization chamber coupled with a neutron-insensitive gamma-ray dosimeter as the working national standard. Using neutrons with an energy of 15 MeV, this method of neutron dosimetry will be compared against a TE calorimeter, and against neutron kerma determined from monoenergetic neutron fluence measurement combined with calculated kerma factors to obtain a check between three independent methods of neutron absorbed dose determination. The comparison of the ionization chamber and fluence methods will be performed using the monoenergetic neutrons obtained from the NBS 3-MV positive-ion Van de Graaff accelerator. The comparison of the ionization chamber and calorimetric methods will require very high neutron dose rates due to the lower sensitivity of calorimeters and will be performed at a suitable remote site. Agreement between the three independent methods, and intercomparisons with the Bureau International des Poids et Mesures and with other national standards laboratories, will assure the accuracy and consistency of the U. S. dosimetry standards for neutron therapy. The properties of all dosimeters for this project have been studied, and the instruments have been calibrated twice. At the time of writing, a comparison with BIPM instruments is in progress.

The experimental standards program will be supported by a theoretical neutron dosimetry program aimed at improving the knowledge of physical data and the correction factors needed to interpret the experimental measurements. Such data and factors include: kerma factors, W (mean energy per ion pair), and mass stopping powers.

SPONSORED WORKSHOPS, CONFERENCES, AND SYMPOSIA

Division 536, Ionizing Radiation

B. M. Coursey, D. D. Hoppes, and L. L. Lucas organized a meeting of commercial suppliers of radioactivity calibration materials, representatives of nuclear power plant radiochemistry departments, NRC enforcement personnel, and officers of the Atomic Industrial Forum to discuss possible NBS involvement in quality assurance programs for power-plant monitoring. NBS, February 3, 1986.

Symposium "Antioxidants" organized by M. S. Simic at the 34th Radiation Research Society Annual Meeting at Las Vegas, Nevada, April 13-17, 1986.

W. L. McLaughlin sponsored workshop on Electron Beam Dosimetry for Association for the Advancement of Medical Instrumentation (AAMI), May 19, 1986.

NBS, Laboratoire Metrologie des Rayonnements Ionisants, and International Committee for Radionuclide Metrology co-sponsored Low-level Environmental Radionuclide Metrology Symposium of the International Committee for Radionuclide Metrology, Grenoble, France, June 3, 1985. (Proceedings Published as EML Report No. 452, editors H.L. Volchok, J. M. R. Hutchinson and N. A. Chieco.)

Stephen M. Seltzer organized and co-chaired with J. W. Behrens two invited/contributed sessions, "Charged-Particle Transport Calculations: Methods and Applications, I and II," at the annual meeting of the American Nuclear Society, Reno, Nevada, June 15-20, 1986.

CRR conducted a full day workshop on Food Irradiation Technology for a group of about 50 Food and Drug Administration plant inspectors. It was organized and chaired by J.C. Humphreys. Senior CRR staff covered such topics as basic radiation interaction mechanisms, effects of radiation on biological materials, radiation processing plant operations, quality control procedures, calibration and use of dosimetry systems, and aspects of health physics in processing plants. Tours of several radiation and research facilities were conducted, NBS, July 24, 1986.

INVITED TALKS

Division 536, Ionizing Radiation

Berger, M. J., "Energy Loss and Range of Electrons," IAEA Advisory Group Meeting on Nuclear and Atomic Data for Radiotherapy and Radiobiology, Rijswijk, The Netherlands, September 16-20, 1985.

Bergtold, D., "Analysis of DNA Damage and Repair During Aging," Gerontology Research Center, National Institute of Aging, Baltimore, MD, March 18, 1986.

Calhoun, J. M., "The Role of Radioactivity Reference Materials in the Quality Assurance of Radiopharmaceuticals," The Laboratory Instrument and Equipment Conference and Exhibition, Chicago, Illinois, October 1, 1985.

Carlson, A. D., "Nuclear Data Standards for ENDF/B-VI," Nuclear Data Section of the International Atomic Energy Agency, Vienna, Austria, January 3, 1986.

Carlson, A. D., "Status of the ENDF/B-VI Standards," CSEWG Meeting, Brookhaven National Laboratory, Upton, NY, May 23, 1986.

Caswell, R. S., "Scientific Activities of the Committee on Interagency Radiation Research and Policy Coordination," Board on Radiation Effects Research, National Academy of Sciences, Washington, D.C., December 6, 1985.

Caswell, R. S., "Scientific Activities of the Committee on Interagency Radiation Research and Policy Coordination," White House Science Panel Briefing, NEOB, Washington, D.C., March 21, 1986.

Caswell, R. S., (with J. J. Coyne, H. M. Gerstenberg, and R. B. Schwartz), "Refinement of Neutron Energy Deposition and Microdosimetry Calculations," International Conference on Fast Neutron Physics, Dubrovnik, Yugoslavia, May 27, 1986.

Caswell, R. S., "Neutron Energy Deposition in Biological Materials," Institute for Medicine, Kernforschungsanlage, Jülich, West Germany, June 3, 1986.

Caswell, R. S., "Neutron Energy Deposition in Biological Materials," Central Bureau of Nuclear Measurements, Euratom, Commission of the European Communities, Geel, Belgium, June 11, 1986.

Collé, R. "Development of Transfer Standards for Radon Measurements," Physics Department, Colorado State University, Fort Collins, CO, September 24, 1985.

Collé, R. "Measurement Uncertainties: Philosophies, Theories and the Role of Subjective Estimation," Graduate School of Public Health, University of Pittsburgh, January 29, 1986.

Collé, R. "Views on the Meaning and Treatment of Measurement Uncertainties," Western Pennsylvania Chapter of the Health Physics Society, Pittsburgh, PA, January 29, 1986.

Collé, R. "NBS Radon Measurement Standards," Conference on Indoor Radon in the Mid-Atlantic States, George Mason University, Fairfax, VA, May 13, 1986.

Collé, R. "Panel on Measurement Uncertainties," 1986 International Conference on Precision Electromagnetic Measurements, NBS, Gaithersburg, MD, June 27, 1986.

Coursey, Bert M., "Standardization of Radionuclides by the Method of $4\pi\beta$ Liquid Scintillation Efficiency Tracing," American Chemical Society, Memphis, Tennessee, October 9, 1985.

Coursey, B. M., "The Standardization of Pure-Beta-Particle Emitting Radionuclides," American Nuclear Society Meeting, November 12, 1985.

Coursey, B. M., "Standardization of Radionuclides Using Liquid Scintillation Counting Techniques," Beckman Instruments, Fullerton, CA, April 19, 1986.

Coyne, J. J., "Secondary Charged Particle Spectra and Kerma Calculations," IAEA Advisory Group Meeting on Nuclear and Atomic Data for Radiotherapy an Radiobiology, Rijswijk, The Netherlands, September 16-20, 1985.

Dizdaroglu, M., "Oxidative Base Damage in DNA," University of Medicine, New Jersey Medical School, Newark, NJ, October 23, 1985.

Dizdaroglu, M., "Characterization of Oxidative Base Damage to DNA," Gerontology Research Center, National Institute of Aging, Baltimore, MD, March 18, 1986.

Dizdaroglu, M. "The Use of Gas Chromatography-Mass Spectrometry for Characterization of DNA Base Damage at Low Radiation Doses," The 34th Annual Meeting of the Radiation Research Society, Las Vegas, NV, April 14, 1986.

Dizdaroglu, M., "Radiation-Induced Damage to DNA and Its Detection at Low Radiation Doses," Health and Safety Research Division, Oak Ridge National Laboratory, Oak Ridge, TN, April 21, 1986.

Dizdaroglu, M., "Detection of Free Radical-Induced Damage to DNA at Biologically Relevant Levels," The Johns Hopkins University, School of Hygiene and Public Health, Baltimore, MD, April 24, 1986.

Dizdaroglu, M., "Detection of Radiation-Induced Damage to DNA at Low Radiation Doses," Cancer Research Campaign, Gray Laboratory, Mount Vernon Hospital, Northwood, Middlesex, UK, July 10, 1986.

Dizdaroglu, M., "Characterization of Radiation-Induced Damage to DNA," Lawrence Berkeley Laboratory, Berkeley, CA, July 24, 1986.

Dizdaroglu, M., "Radiation-Induced Formation of Cyclic-Purine Nucleosides in DNA," Lawrence Berkeley Laboratory, Berkeley, CA, July 25, 1986.

Gilliam, D. M., "Absolute Neutron Flux Determination--A Problem for the Measurement of τ_n," Workshop on the Investigation of Fundamental Interactions with Cold Neutrons, NBS, Gaithersburg, MD, November 14, 1985.

Goodman, L. J., "Neutron Dosimetry," Radiobiology Concepts Lecture, Armed Forces Radiobiology Research Institute, Bethesda, MD, October 15, 1985.

Grundl, J. A., "Pursuing Public and Professional Perception of Nuclear Energy With the Smithsonian Lady Godiva Replica and Demonstration/Display," Banquet Presentation at Fast Burst Reactor Workshop, Albuquerque, NM, April 7, 1986.

Hoppes, D. D., "Gamma-Ray Spectrometry," "NBS Radioactivity Measurements," and "U.S. Traceability Requirements for Radioactivity Measurements," Institute of Atomic Energy (Beijing), Shaanxi Provincial Research Institute for Preventive Medicine, Sichuan University, and the National Institute of Metrology (Beijing), China, October 10-21, 1985.

Hoppes, D. D., "Gamma Spectroscopy and Related Activities in the National Bureau of Standards Radioactivity Group," Nuclear Data Users' Group Meeting, Southport, North Carolina, May 14, 1986.

Hubbell, J. H., "Radiation Physics Programs at the NBS," Rudjer Boskovic Institute, Zagreb, Yugoslavia, October 10, 1985.

Hubbell, J. H., "Photon Cross Sections 1 keV to 100 GeV: Current NBS Compilation," American Nuclear Society Winter Meeting, San Francisco, California, November 11, 1985.

Hubbell, J. H., "Nuclear Cross Sections and Their Applications," Student Chapter, American Nuclear Society, U.S. Naval Academy, Annapolis, MD, December 5, 1985.

Hutchinson, J. M. R., "Low-level Radioactivity Measurements at NBS," Instituto de Radioprotecao E Dosimetria, Rio de Janeiro, Brazil, October 2, 1985.

Hutchinson, J. M. R., Inn, K. G. W., Parks, J. E., Beekman, D. W., Spaar, M. T., and Fairbank, W. M., "Investigation of Matrix Effects or Isotope Dilution in SIRIS Measurement of Uranium in Soils," Advanced Laser Technology for Chemical Measurement Workshop, Seattle, WA, April 28, 1986.

Hutchinson, J. M. R., Lucatorto, T. B., and Witaker, T. L., "Exploiting the Optical Isotope Shift for Ultrasensitive Isotopic Analysis with Lasers," American Nuclear Society, Reno, NV, June 26, 1986.

Hutchinson, J. M. R., Parks, J. E., Beekman, D. W., Moore, L. J., Schmitt, H. W., Sparr, M. T., Taylor, E. H., and Fairbank, W. M., "Progress in Analysis by Sputter Initiated Resonance Ionization Spectroscopy," Third International Symposium on Resonance Ionization Spectroscopy," Swansea, UK, September 7, 1986.

Inn, Kenneth G. W., "The National Bureau of Standards Natural-matrix Environmental-level Radioactivity Standard Reference Materials," Low Level Measurements of Actinides and Long-lived Radionuclides in Biological and Environmental Samples Meeting, Lund, Sweden, June 10, 1986.

Johnson, R. G., "Multi-Particle Accelerator for Neutron and High-LET Radiation Research," IAEA Advisory Group Meeting on Neutron Source Properties, Leningrad, USSR, June 9, 1986.

Johnson, R. G., "Detectors for Neutron Scattering in the eV Region," Condensed Matter Physics Seminar, Rutherford Appleton Laboratory, Didcot, UK, June 18, 1986.

Lamaze, G. P., "Calibration and Applications of NBS Standard Neutron Fields," Univ. of Virginia, Dept. of Nuclear Engineering and Engineering Physics - Seminar, Charlottesville, VA, February 6, 1986.

Loevinger, R., "The NBS Primary Standard of Absorbed Dose," Radiation Science Seminar, Georgetown University Graduate School, Washington, DC, October 2, 1985.

Loevinger, R., "Quantities, Units, and Standards for Radiology," Annual Meeting of the American Association of Physicists in Medicine, Lexington, KY, August 4, 1986.

McGarry, E. D., "LWR-PV Surveillance Dosimetry Improvement Program Overview," Fourteenth Water Reactor Safety Information Meeting, NBS, October, 1985.

McLaughlin, W., "Food Irradiation Technology Overview," Preservation Technology Meeting, FMC Central Engineering Laboratories, Santa Clara, CA, September 26, 1985.

McLaughlin, W., "High-Dose Dosimetry," UK Panel on Gamma-Ray and Electron Irradiation, University of Oxford, Oxford, England, October 3, 1985.

McLaughlin, W., "Radiochromic Response to Ionizing Radiation: Kinetics and Temperature Effects," Chemistry Division Seminar, Atomic Energy Research Establishment, Harwell, England, October 7, 1985.

McLaughlin, W., "Radiation Dosimetry by Means of Infrared Spectrophotometry of Polyethylene," Physics Dept. Seminar, Royal Military College of Science, Shrivenham, England, October 11, 1985.

McLaughlin, W., "Dosimetry as a Means of Quality Control in Industrial Radiation Sterilization," to the staff of IOTECH, Inc., Northglen, Colorado, October 1, 1985.

McLaughlin, W., "Dyed Cellulosics for High-Dose Dosimetry," Laboratory for Radiation and Polymer Science, University of Maryland, College Park, MD, December 4, 1985.

McLaughlin, W., "Dosimetry as a Means of Quality Control in Electron Beam Sterilization of Medical Devices," Meeting of the Sterilization Standards Committee of Association for the Advancement of Medical Instrumentation, Hyatt Arlington, Arlington, VA, January 21, 1986.

McLaughlin, W., "Dosimetry for Regulatory and Routine Control in Radiation Applications," Departments of Energy, Health, and Environment in Bangkok, Thailand, March 7, 1986.

McLaughlin, W., "Dosimetry for Measurement Quality Assurance," Division of Foods, International Atomic Energy Agency, Vienna, Austria, March 19, 1986.

McLaughlin, W., "Real-time Telemetering of Dosimetry Data for Radiation Processing Applications," Chemistry Division, AERE Harwell, Atomic Energy Research Establishment, Harwell, Oxfordshire, UK, June 13, 1986.

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Warasawas, W., and McLaughlin, W. L., High-Dose Dosimetry by Sublimation of Crystalline Organic Compounds (to be submitted to Radiation Physics and Chemistry).

Wasson, O. A., Recent Fission Cross Section Standards, Proceedings of the XVth International Symposium on Nuclear Physics-Nuclear Fission, Gaussig, German Democratic Republic (in press).

Weaver, J. T., Loftus, T. P., and Loevinger, R., Calibration of Brachytherapy Sources at the National Bureau of Standards, NBSIR and NBSSP (in preparation).

Williams, J., Cogburn, C., Hodgson, L., West, L., McGarry, E. D., Lamaze, G., Gilliam, D., Grundl, J., Coursey, B., Rogers, J. W., and Gherke, R., Measurements of Fission Spectrum Averaged Cross Sections for the $^{93}Nb(n,n')^{93}Nb$ Reaction (in preparation).

Williamson, T. G., Lamaze, G. P., and Gilliam, D. M., Calibration of a Neutron Driven Gamma Ray Source, (in preparation).

Williamson, T. G., Ayers, T. A., Hammersten, W. L., and Lamaze, G. P., Nb(n,n') Cross Section Measurement in a Fission Spectrum (in preparation).

Williamson, T. G., Lamaze, G. P., Gilliam, D. M., and Eisenhauer, C. M., Iron and Cadmium Capture Gamma Ray Photofission Measurements, American Nuclear Society Topical Conference on Theory and Practice in Radiation Protection and Shielding.

TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION AND LEADERSHIP

Division 536, Ionizing Radiation

James W. Behrens

Member, Cross Section Evaluation Group Committee on Data Status Requests (CSEWG).

Chairman, Nuclear, Atomic, and Radiation Committee, Isotopes and Radiation Division, American Nuclear Society.

Chairman, Transuranic Task Force, Isotopes and Radiation Division, American Nuclear Society.

Chairman, Organizing Committee, Topical Conference on Fifty Years With Nuclear Fission to be held at NBS April 26-28, 1989; cosponsors are NBS and ANS, at present.

Martin J. Berger

Member, International Atomic Energy Agency Advisory Group on Nuclear and Atomic Data for Radiotherapy and Radiobiology.

Chairman, International Commission on Radiation Units and Measurements (ICRU), Committee on Stopping Power.

Member, National Council on Radiation Protection and Measurements (NCRP) Committee #52 on Conceptual Basis on Dosimetry.

Member, NCRP Committee #55 on Experimental Verification of Internal Dosimetry.

Member, Naval Research Advisory Committee, Naval Surface Weapons Center Review Panel.

Jacqueline M. Calhoun

Member, National Measurements Laboratory Minority Advisory Panel.

EEO Counselor, NBS, two-year appointment, January 19, 1984 through January 19, 1986.

Allan D. Carlson

Member, Cross Section Evaluation Working Group (CSEWG).

Member, Evaluation Committee of CSEWG.

Division 536, Technical and Professional Committee Participation and Leadership (cont'd.)

Allan D. Carlson (cont'd.)

Chairman, Standards Subcommittee, CSEWG.

Member, Data Status and Requests Subcommittee of CSEWG.

Randall S. Caswell

Chairman, Science Panel, Committee on Interagency Radiation Research and Policy Coordination (CIRRPC), Office of Science and Technology Policy.

Alternate Member, CIRRPC, Office of Science and Technology Policy.

Member, Consultative Committee for Ionizing Radiations (CCEMRI), Conférence Générale des Poids et Mesures, Paris, France.

Chairman, Section on Neutron Measurements (Section III), CCEMRI, Conférence Générale des Poids et Mesures, Paris, France.

Member, National Council on Radiation Protection and Measurements (NCRP).

Member and Secretary, International Commission on Radiation Units and Measurements (ICRU).

Sponsor, ICRU Report Committee on Stopping Power.

Sponsor, ICRU Report Committee on Absolute and Relative Dosimetry at High Doses.

Sponsor, ICRU Report Committee on Material Equivalent and Tissue Substitutes.

Sponsor, ICRU Report Committee on C_λ.

Sponsor, ICRU Report Committee on Characterization of Irradiation for Materials Effect Studies.

Sponsor, ICRU Report Committitee on Clinical Dosimetry for Neutrons (Physics).

Member, Radiation Research Accelerator Facility (RARAF) Scientific Advisory Committee, Columbia University.

Member, Program Committee for the Sixth Symposium on Neutron Dosimetry, Munich (Neuherberg), October 12-16, 1986.

Division 536, Technical and Professional Committee Participation and Leadership (cont'd.)

Randall S. Caswell (cont'd.)

Member, Organizing Committee, Second International Conference on Anticarcinogenesis and Radiation Protection, March 8-12, 1987.

Ronald Collé

Member, Science Subpanel on Radon Protection and Health Effects, Committee on Interagency Radiation Research and Policy Coordination.

Member, Radon Working Group, Interagency Committee on Indoor Air Quality.

Chairman, International Standards Organization, Working Group on Expression of Measurement Uncertainties.

Bert M. Coursey

Member, International Committee for Radionuclide Metrology (ICRM) Life Sciences Working Group.

Member, ANSI Committee N42.02 on Nuclear Instruments, Procedural Standards for Calibration of Detectors for Radioactive Measurements.

J. Joseph Coyne

Member, CIRRPC Subcommittee on High LET Radiation.

Member, European Community Dosimetry Group (EURADOS) Committee 1: Tissue-Equivalent Proportional Counters as an Instrument for Radiation Protection.

Member, EURADOS Committee 4: Computational Methods and Benchmark Calculations in Radiation Protection.

Member, International Atomic Energy Agency Advisory Group on Nuclear and Atomic Data for Radiotherapy and Radiobiology.

Charles E. Dick

Member, Technical Organizing Committee, International Conference on the Application of Accelerators in Research and Industry, Biannual conference held in even numbered years at North Texas State University, Denton, Texas.

Division 536, Technical and Professional Committee Participation and Leadership (cont'd.)

Charles M. Eisenhauer

Member, CIRRPC Science Panel.

Member, National Council on Radiation Protection and Measurements (NCRP) Task Group on Atomic Bomb Survivor Dosimetry: SC-40 Biological Aspects of Radiation Protection Criteria.

Member, ASTM Subcommittee E10.05 on Nuclear Radiation Metrology.

Member, NAS-NRC Advisory Committee on the Radiation Effects Research Foundation Subcommittee: Panel on the Reassessment of A-Bomb Dosimetry.

Member, ANS Standards Committee Working Group on Gamma-Ray Attenuation Data.

Elmer H. Eisenhower

Alternate Representative, ANSI N44, Equipment and Materials for Medical Radiation Applications.

Chairman, ANSI N43, Equipment for Non-Medical Radiation Applications.

Chairman, Interagency Committee on Occupational Radiation Protection Measurements.

Resource Person, Conference of Radiation Control Program Directors, Committee on Radiation Measurements.

Department of Commerce Representative, Interagency Working Group on Occupational Exposure Guidance.

Member, ASTM Subcommittee E10.04 on Radiation Protection Methodology.

Chairman, ASTM Task Group E10.07.05 on Performance of Calibration Laboratories for Radiation Dosimetry in Industrial Testing and Processing.

Member, ASTM Committee E10 on Nuclear Technology and Applications.

Member, Science Subpanel on Scientific Basis for Radiation Protection Standards, Committee on Interagency Radiation Research and Policy Coordination.

Division 536, Technical and Professional Committee Participation and Leadership (cont'd.)

Elmer H. Eisenhauer (cont'd.)

Member, Committee on Secondary Calibration Laboratories for Survey Instruments, Health Physics Society.

Leon J. Goodman

Member, Report Committee on Clinical Dosimetry for Neutrons, International Commission on Radiation Units and Measurements.

Consultant, Report Committee on Material Equivalents and Tissue Substitutes, International Commission on Radiation Units and Measurements.

Consultant, American Association of Physicists in Medicine, Radiation Therapy Committee Task Group No. 18, Fast Neutron Beam Dosimetry Physics.

James A. Grundl

Member, Steering Committee for Developing ASTM Standards for Reactor Dosimetry, NBS, March 1985.

Member, ASTM Subcommittee E10.05 on Nuclear Radiation Metrology.

Secretary, Steering Committee for Lady Godiva Display at the National Atomic Museum.

H. Thompson Heaton, II

Alternate Representative, ANSI N43, Equipment for Non-Medical Radiation Applications.

Member, ANSI N43-3, Subcommittee for Gamma Irradiators.

Member, ANSI N43-9, Subcommittee for Electron Microscopes.

Resource Person, Conference of Radiation Control Program Directors, Committee on Radiation Measurements.

Dale D. Hoppes

Member, International Committee for Radionuclide Metrology (ICRM) Alpha-, Beta, and Gamma-Ray Spectrometry Working Group.

Member, Atomic Industrial Forum (AIF)-NBS Standards Program Committee.

Division 536, Technical and Professional Committee Participation and Leadership (cont'd.)

Dale D. Hoppes (cont'd.)

Member, International Committee of Weights and Measures (BIPM), Consultative Committee on Standards for Measuring Ionizing Radiations, Subcommittee Section II: Radionuclide Measurements.

Member, ANSI Subcommittee N42.2 on Procedural Standards for Calibration of detectors for Radioactive Materials.

John H. Hubbell

Chairman, General Radiation Protection Section, Health Physics Society Standards Committee.

Chairman, American Nuclear Society (ANS) Radiation Protection and Shielding Division, ANS-6 Ad Hoc Committee on SI Units,

Member, ANS Isotopes and Radiation Division Nuclear, Atomic, and Radiation Data Committee; Organizer and Chairman of sponsored sessions: "Atomic and Radiation Data and Applications," for November 1987 ANS Meeting.

Member, ANS Isotopes and Radiation Division Industrial Radiation Measurement Applications Committee.

Executive Councilor, International Radiation Physics Society.

Secretary, X-ray Absorption Task Group, International Union of Crystallography Commission on Crystallographic Apparatus.

Member, Cross Section Evaluation Working Group (CSEWG) Subcommittee on Shielding.

J. C. Humphreys

Secretary, ASTM E10.07 Subcommittee on Ionizing Radiation Dosimetry and Radiation Effects on Materials and Devices.

Member, ASTM F1.11 on Electronics Hardness Assurance and AAMI (Association for the Advancement of Medical Instrumentation) subcommittee on radiation sterilization of medical devices and products.

J. M. Robin Hutchinson

Chairman, International Committee for Radionuclide Metrology (ICRM) Subcommittee on Low-Level Techniques.

Division 536, Technical and Professional Committee Participation and Leadership (cont'd.)

J. M. Robin Hutchinson (cont'd)

Member, American National Standards Institute (ANSI) Committee on Nuclear Instruments and Detectors.

Secretary, ANSI Subcommittee N42.2 on Procedural Standards for Calibration of Detectors for Radioactivity Measurements.

Kenneth G.W. Inn

Member, ASTM Committee C26.05.01 Methods of Test, Test Methods, Environmental Methods.

George P. Lamaze

Vice-Chairman and Acting Secretary, American Society for Testing and Materials (ASTM), Subcommittee E10.05, Nuclear Radiation Metrology.

Chairman, Membership Subcommittee, ASTM Committee E10, Nuclear Technology and Applications.

Secretary, Planning Committees for the 6th ASTM-Euratom Symposium on Reactor Dosimetry.

Robert Loevinger

Member, BIPM Consultative Committee for Standards for Measurement of Ionizing Radiation, Section I, X- and Gamma-Rays and Electrons.

Member, Medical International Radiation Dose Committee, Society of Nuclear Medicine.

Consultant, American Association of Physicists in Medicine (AAPM) Radiation Therapy Committee.

Member, AAPM Radiation Therapy Committee Task Group 3, Accredited Dosimetry Calibration Laboratories.

Member, AAPM Radiation Therapy Committee Task Group 32, Brachytherapy.

Wilfrid B. Mann

Consultant, International Commission on Radiation Units and Measurements (ICRU).

Division 536, Technical and Professional Committee Participation and Leadership (cont'd.)

Wilfrid B. Mann (cont'd)

Member, ANSI-INMM Work Group INMM 8.04 Calibration Technique for the Calorimetric Assaying of Plutonium-Bearing Solids applied to Nuclear Materials Control.

Honorary Council Member, National Council on Radiation Protection and Measurements (NCRP).

Chairman, NCRP Committee 18A on Standards and Measurement of Radioactivity for Radiological Use.

Life Member, International Committee for Radionuclide Metrology.

Emmert D. McGarry

Member, ASTM Committee E10; Subcommittee E10.05 on Nuclear Radiation Metrology.

Chairman, Awards Committee of ASTM Subcommittee E10.05.

Member, Planning Committee for the 6th ASTM-Euratom Symposium on Reactor Dosimetry.

William L. McLaughlin

Chairman, International Commission on Radiation Units and Measurements (ICRU), Committee on Absolute and Relative Dosimetry at High Doses.

Technical Advisor, ICRU Committee on Chemical Dosimetry.

Member, American Nuclear Society (ANS), Subcommittee for Nuclear Terminology and Units, ANS-9.

Chairman, ANS-9.1 Subcommittee, Health Physics and Dosimetry.

Member, ASTM E10.07, Ionizing Radiation Dosimetry and Radiation Effects on Materials and Electronic Devices.

Technical Advisor, Association for the Advancement of Medical Instrumentation, Subcommittee on Radiation Sterilization of Medical Devices, Task on Radiation Dosimetry.

Member, ANS 9.2, Subcommittee on Shielding of the Nuclear Terminology.

Division 536, Technical and Professional Committee Participation and Leadership (cont'd.)

William L. McLaughlin (cont'd)

Technical Advisor, ISO WG-1, Nuclear Energy Terminology, Task on the ISO TC/85, Committee on Nuclear Energy.

Technical Advisor, Council of Europe Parliamentary Assembly, Work Group on Aerospace Physiology, Medicine, and Radiation Measurement.

Technical Advisor, Council of Europe Parliamentary Assembly, Work Group on Space Biophysics.

Member, R & D Associates Committee on Irradiated Food Products.

Member, International Atomic Energy Agency, Advisory Group on High Dose Measurement and Standardization for Radiation Processing.

Member, Association for Advancement of Medical Instrumentation, Working Group on Radiation Sterilization Dosimetry.

Technical Advisor, National Council on Radiation Protection and Measurement, Scientific Committee 63, Radiation Exposure Control in a Nuclear Emergency.

Science and Technology Consultant, Committee on Interagency Radiation Research and Policy Coordination (CIRRPC).

Member, Advisory Panel on Electron Beam Dosimetry for Industrial Radiation Processing, International Atomic Energy Agency.

Member, Organizing Committee, International Workshop on Identification and Dosimetry of Irradiated Food, Federal Republic of Germany's Office of Radiation and Environmental Health and Federal Health Office, November 16-21, 1986.

Member, Industrial Panel on Status of Electron and Gamma-Ray Dosimetry for Radiation Processing.

Member, Organizing and Program Committees, 6th International Conference on Radiation Processing, Ottawa, Canada, May 31- June 5, 1987.

Robert C. Placious

Advisor to Center for NDE, Iowa State University, Ames Iowa.

Division 536, Technical and Professional Committee Participation and Leadership (cont'd.)

Robert B. Schwartz

Member, International Standards Organization (ISO) Technical Committee 85 (Nuclear Energy), Subcommittee 2 (Radiation Protection), Working Group 2 (Reference Radiations).

Member, International Commission on Radiation Units and Measurements (ICRU) Report Committee on Measurements of Dose Equivalent.

Stephen M. Seltzer

Member, International Commission on Radiation Units and Measurements (ICRU), Committee on Stopping Power.

Michael P. Unterweger

Member, ASTM Committee D22 on Sampling and Analysis of Atmospheres.

Oren A. Wasson

Member, Department of Energy Nuclear Data Committee.

MAJOR CONSULTING AND ADVISORY SERVICES

Division 536, Ionizing Radiation

A. Carlson reviewed a neutron detector program for the DOE Small Business Innovation Research Program.

R. Collé, as part of an informal advisory task force, assisted the U.S. Environmental Protection Agency in establishing a radon/radon progeny measurement proficiency evaluation and quality assurance program.

R. Collé advised and assisted staff members in various NBS Divisions on the treatment and reporting of measurement uncertainties.

C. E. Dick consulted with Dr. M. J. Moran, Lawrence Livermore National Laboratory, Livermore, CA on the use of low energy Van de Graaff Accelerators in the production of coherent transition and Smith Purcell radiation.

C. E. Dick consulted with Mr. H. E. Boesch, Harry Diamond Laboratory, White Oak, MD on the use of electron beams for radiation hardness testing of electronic components.

C. E. Dick consulted with members of the Center for Chemical Physics, NBS on the utilization of the pulsed electron Van de Graaff beam for experimental programs in pulsed radiolysis.

C. E. Dick consulted with B. Rich, L. Johnson, D. Martz, EG&G, Idaho Falls National Engineering Laboratory (INEL), Idaho Falls, Idaho on calibration of beta-ray spectrometers, survey instruments and extrapolation chambers.

C. E. Dick consulted with Dr. H. Mendlowitz and Dr. S. Glass, Howard University, Washington, DC, on coherence effects in Cherenkov radiation.

S. R. Domen consulted with G. K. Svensson of the Radiation Therapy Department, the Harvard Medical School, who needed detailed advice on construction of a water calorimeter for measurement of absorbed dose.

E. H. Eisenhower performed an analysis for the Federal Emergency Management Agency of a problem with sealed radiation sources that were leaking. His analysis helped to convince the supplier to replace all of the procured sources.

E. H. Eisenhower responded to a request from the Nuclear Regulatory Commission to evaluate proposed new regulations and suggest an improved version.

D. M. Gilliam advised and assisted Babcock and Wilcox (B&W) in preparation of high-level dosimeters for measurements in mixed gamma and neutron radiation fields at commercial nuclear reactors. These measurements are being made for assessing the integrity of reactor pressure vessels and understanding radiation shielding for reducing personnel exposure.

D. M. Gilliam and G. P. Lamaze carried out tightly scheduled tests on new neutron counters developed at Lawrence Livermore National Laboratory for use in underground weapons tests at the Nevada test range.

D. M. Gilliam developed new exposure room neutron monitors for the Armed Forces Radiobiological Research Institute reactor.

H. T. Heaton, II advised New York Power Authority on procedures for setting up a radiation calibration laboratory and on a method for calibrating their electrometer.

H. T. Heaton, II consulted with Conam Inspection on appropriate methods they could use to determine the field from their gamma source.

H. T. Heaton, II consulted with Commonwealth Edison on radiation instrument calibration and QA procedures.

H. T. Heaton, II advised Oak Ridge National Laboratory on procedures for setting up a radiation calibration laboratory for photons.

J. C. Humphreys and W. L. McLaughlin advised the upper management of FMC Corporation, San Jose, California, on the relative merits of radiation processing of food products in order to help them decide whether FMC should be heavily involved in this new industry.

K. G. W. Inn participated in meetings to evaluate the state-of-the-art bioassay as a measure of radiation exposure with emphasis on time and factors. He participated in the following meetings:

DOE Radiobioassay and Internal Dosimetry Workshop, Albuquerque, NM, January 20-27, 1986.

Task group meetings of the Oak Ridge Associated Universities for the National Cancer Institute, Albuquerque, NM, February 10-11, 1986; Washington, DC, May 12-13, 1986; Oak Ridge, TN, April 8-10, 1986; and Albuquerque, NM, September 15-18, 1986.

Track Etch Analysis evaluation meeting for the National Cancer Institute, Brookhaven National Laboratory, NY, July 29-30, 1986.

P. J. Lamperti provided consultation to the Federal Emergency Measures Agency; to the Department of the Army, Redstone Arsenal; and to E.G.&G., Idaho Falls; concerning selection of instruments and beam qualities for various radiation studies and calibrations.

R. Loevinger served as consultant to the Dosimetry Section of the International Atomic Energy Agency at a meeting of the Scientific Committee of the Secondary Standard Dosimetry Laboratory Network, in Vienna, Austria, May 12-16, 1986.

E. D. McGarry participated in the absolute power calibration of a special non-proliferation core tested by Argonne National Laboratories at Oak Ridge National Laboratory.

E. D. McGarry provided consultation and ^{235}U deposit calibration for special Cadarache-built fission chambers used in the non-proliferation core-power measurement.

E. D. McGarry provided consultation to Materials Engineering Branch of the Nuclear Regulatory Commission regarding benchmarking of pressure vessel surveillance dosimetry.

W. L. McLaughlin and J. C. Humphreys advised Travenol Laboratories, Round Lake, Illinois, on specific performance characteristics of various dosimetry systems and quality assurance procedures used by the company to produce sterilized medical goods.

W. L. McLaughlin, Dr. George Hsieh, FMC Corp., Santa Clara, CA. With J. C. Humphreys, assisted in briefing staff at FMC on radiation processing technology and food irradiation processing.

W. L. McLaughlin, Dr. Dan Sloan, Dr. Marshall Cleland, IOTECH, Inc., Northglen, CO. Supplied temperature-dependence data for response of radiation processing dosimeters, namely radiochromic films, red Perspex, and Fricke dosimeters.

W. L. McLaughlin, Alicia Jarboe, Food Safety Inspection Service, USDA. Supplied food irradiation information and dosimetry procedures for measurement quality assurances.

W. L. McLaughlin, Dr. Stan Stern, Naval Surface Center, White Oak, MD. Provided wide-dose-range dosimetry systems and data, for emergency dose mapping of personnel areas. Described NBS calibration and special dosimetry services.

W. L. McLaughlin, Dr. William Murray, National Electrical Manufacturers Association. Detailed discussion of high resolution radiation imaging and diagnostics systems and methods for precise measurement of output of radiation sources and for both diagnostic imaging and cancer therapy.

W. L. McLaughlin, Thomas Fisher, Radiation Sterilizers, Inc., Atlanta, GA. Described detailed procedures for correcting high-dose dosimeter response for temperature dependence, in order to improve on-line dosimetry accuracy in radiation processing.

W. L. McLaughlin, Dr. Barry Fairand, Radiation Sterilizers, Inc., Westerville, OH. Provided a white paper on the energy dependence of dosimeter response and an argument for the use of ^{60}Co calibration in ^{137}Cs irradiator applications, without the need for energy-dependence correction factors.

W. L. McLaughlin, Dr. Louise Miles, Naval Surface Weapons Center, White Oak, MD. Supplied their dosimetry group with calibrated opti-chromic dosimeters and literature for use in fast retrieval of dose mapping data in naval facilities.

W. L. McLaughlin, Dr. Scott Smith, North American Science Associates, Northwood, OH. Provided them with radiochromic dye solutions for monitoring the irradiation of microbial samples, in order to devise a protocol in the study of survival curves in microbiological studies.

W. L. McLaughlin, Dr. James Love, 3M Co., St. Paul, MN. Devised a means for electron beam dosimetry in samples passing a very high speed under extended low-energy (190 keV) electron beams.

W. L. McLaughlin, Dr. Michael Terpilak, Nuclear Lectern Associates, Columbia, MD. Devised a means for standardizing the irradiation of alkali halide powder samples to high doses of gamma radiation.

W. L. McLaughlin, Dr. Clement Bourgault, Insul-Tab, Inc. Determined response characteristics of dyed cellulose diacetate film dosimeters for very high doses of low-energy electron beams.

W. L. McLaughlin, Dr. Elaine Boudos, IRT Corp., San Diego, CA. Supplied temperature dependence data and test procedures for radiochromic film dosimeters, for use in linac electron beams, for applications in doping of semi-conductors and lithography.

W. L. McLaughlin, Dr. Vincent Lasko, Johnson and Johnson, Co., East Windson, NJ. Devised a means of 3-dimension dose mapping in wide webbings irradiated on a belt conveyor using 0.8 MeV electron beams.

W. L. McLaughlin, Dr. Becky M. Eubank and M. G. Arudi, 3M Co., Memory Technologies Group, St. Paul, MN. Devised a means of continuous, telemetering monitoring of the irradiation processing of wide video and audio tape by low-energy electron beams which resulted in the development of a new film type.

W. L. McLaughlin, Janet New, Datascope Corp., Oakland, NJ. Provided literature and dosimetry methods for sterility control in sterilization of medical devices by ionizing radiation.

W. L. McLaughlin, Dr. Joseph Rothleder, California Department of Food and Agriculture, Sacramento, CA. Supplied a detailed protocol for calibration of food irradiation dosimeters, as a standard test procedure in the regulation of food irradiation plants in California.

W. L. McLaughlin, Ellen Holman, INDA, Association of Navel Fabrics Industry, Washington, DC. Provided detailed information on the use of standardized dosimetry as means of quality control in the radiation processing of textiles.

W. L. McLaughlin, Doris Boesch, ALZA Corp., Palo Alto, CA. Detailed discussions of environmental effects and correction factors for improving the accuracy of chemical dosimeters used in radiation processing.

W. L. McLaughlin, Dr. Arnold Fero, Westinghouse Corp., Pittsburg, PA. Supplied calibrated LiF chip dosimeters and response data for determining large doses and dose mapping data around spent-nuclear fuel elements.

W. L. McLaughlin, Dr. Michael Fogerty, Medical Sterilization, Inc., Syosset, NY. Provided consultation on the response of dye dosimeters and their proper use in electron beam sterilization of medical devices.

W. L. McLaughlin, Dr. George Lotze, National Institutes of Health. Gave invited lecture and consultation on food irradiation technology and methods of measurement quality assurance.

W. L. McLaughlin, Dr. Mel Dollar and Dr. Paisan Loarianie, Food Irradiation Section, IAEA, Vienna. Devised a protocol for standardizing the radiation processing of a variety of food stuff requiring different dose levels and irradiation procedures.

W. L. McLaughlin, Dr. S. V. Nablo, Energy Sciences, Inc., Woburn, MA. Devised a method for correcting for temperature effects in thin-film dosimeters irradiated at very high dose rates with low energy electrons in inert gases and in vacuum.

Division 536, Major Consulting and Advisory Services (cont'd.)

W. L. McLaughlin, Dr. Thomas Keim, General Electric Research & Development Center, Schenectady, NY. Consultation on methods of radiation processing with electron beams, and measurement techniques to achieve quality control.

W. L. McLaughlin, Dr. Marge Bruce, Wyle Laboratories, Huntsville, AL. Provided dosimetry methods and materials for electron beam depth-dose studies and quality control.

W. L. McLaughlin, Dr. R. D. Weir, Boeing Aerospace Company, Seattle, WA. Devised method for standardizing the response of optical-quality lithium fluoride specimens to high doses of gamma rays and electric beams.

W. L. McLaughlin, Dr. Michael Saylor, Isomedix, Inc., Parsippany, NJ. Consultation on dosimetry methods for measurement of absorbed dose at interfaces of different materials.

W. L. McLaughlin, Dr. Marcia Bova, IIT Corp., Knoxville, TN. Described details of method of measurement of absorbed dose by electrochemical methods and selective ion complexing using fluoride ferric ion aqueous solutions.

W. L. McLaughlin, Dr. James Asbrock, Hughes Aircraft Corp., San Diego, CA. Devised a method for mapping and calibrating their large ^{60}Co gamma-ray source.

W. L. McLaughlin, Dr. Roy Modjewski, PPG Industries, Oak Creek, WI. Devised dosimetry methods for measurement of very high doses of low-energy electrons (200 keV), and dose-rate dependence studies.

W. L. McLaughlin, Dr. K. Mizasawa, Nissen High Voltage Co., New York, NY. Consultation on NBS method for measurement of absorbed dose distribution in electron-beam irradiated high voltage wires and cables, using thin radiochromic films.

W. L. McLaughlin, Dr. Alejanda Jaidar and Prof. A. de la Piedad, Department of Physics, University of Mexico. Provided information on electron spin resonance of amino acids and radiation-sensitive dyes for electron beam dosimetry.

W. L. McLaughlin, Dr. Kenneth Hannah, Columbia Research Corp., Gaithersburg, MD. Supplied details of radiochromic and cellophane film response characteristics, as a means of mapping three-dimensional dose distributions in polymers irradiated by 3-MeV electrons.

W. L. McLaughlin, Dr. Thomas Legbandt, Barcel Corporation, Anaheim, CA. Devised a method for measuring depth-dose and iso-dose contours in electron-beam irradiated wire and cable.

W. L. McLaughlin, Ruth Garcia, Harry Schaeffer, Converters, American Hospital Supply Corp., El Paso, TX. Supplied details of temperature dependence and humidity dependence of radiochromic film response.

W. L. McLaughlin, Dr. Robert Davis, South Atlantic Area Stored-Product Insects R&D Lab, USDA. Consultation on dosimetry methods for achieving measurement quality assurance in the radiation disinfestation of grain.

W. L. McLaughlin, Dr. G. M. Meaburn, National Marine Fisheries Service, Charleston, SC. Supplied literature and detailed dosimetry information for food irradiation technology and engineering.

W. L. McLaughlin, Linda Edwards, Chemical Manufacturers Association, Washington, DC. Conducted radio interview on NBS research activities in food irradiation and the development of post-irradiation dosimetry methods.

W. L. McLaughlin, Laura Beck, E-Beam Services, Cranbery, NJ. Provided detailed information on the temperature dependence, humidity effects, and dose-rate effects between electron beam and gamma-ray response of radiochromic dosimeters, as compared with other working dosimeters in radiation processing.

W. L. McLaughlin, Prof. Ralph S. Becker, University of Houston, Houston, TX. Supplied literature and dosimeter materials for chemical dosimetry at high radiation doses.

W. L. McLaughlin, Singer Company, Librascope Division, Glendale, CA. Devised method for irradiation of LiF and LiB_4O_7 over very wide dose and dose-rate ranges.

W. L. McLaughlin, Dr. George L. Tingey, Battelle Northwest, Hamford, WA. Consultation on dosimetry methods for quality control in food irradiation at commercial and pilot plants.

W. L. McLaughlin, Dr. James Forsell, Northern California Transplant Bank, San Francisco, CA. Consultation on the use of standardized dosimetry for sterility control and validation in radiation sterilization of surgical equipment and prosthetic devices.

W. L. McLaughlin, David Stern, Radiation Technology, Inc., Whippany, NJ. Supplied details of several types of chemical dosimeters and how they are used successfully over broad ranges of absorbed dose.

W. L. McLaughlin, Dr. J. Barber, Childrens Hospital, Washington, DC. Assisted in the planning of a transplant experiment, where pharangeal tissue is irradiated prior to implanting.

W. L. McLaughlin, Prof. Brian Methe, Rensselear Polytechnical Institute, Troy, NY. Devised means for accurate irradiation of thermoluminescent alkali halide powders to absorbed doses over wide ranges of doses and dose rates.

W. L. McLaughlin, Dr. Todd Hess, Mead Imaging, Inc., Miamisburg, OH. Assisted the development of a radiation monitor for quality control in industrial radiation curing plants.

W. L. McLaughlin, Dr. Jeffrey Beck, Ethican, Inc., Sommerville, NJ. Provided temperature dependence data and consultation in order to correct response of dosimeters used under extreme environmental conditions in the radiation sterilization of prosthetic devices and surgical sutures.

W. L. McLaughlin, Dr. Lois Jones, Becton-Dickinson Co., Research Triangle Park, NC. Consultation on the design and equipment needs for setting up a central dosimetry laboratory for the company.

W. L. McLaughlin, Acme United Corporation, Fairfield, CN. Consultation on the performance and methods of preparation of aqueous chemical dosimeters (e.g. ferrous-cupric) for standardizing the radiation sterilization of medical gauze products.

W. L. McLaughlin, Dr. Brian Ives, Sion International, Inc., Richland, WA. Provided data and protocols for measurement quality assurance in pilot-scale and production level food irradiation.

W. L. McLaughlin, Dr. Steven Smith, Kendall-McGaa, Irvine, CA. Assisted in setting up dosimetry and dose mapping procedures for assessing quality control in heterogeneous plastic products irradiated by 12 MeV electron beams.

W. L. McLaughlin, Dr. William Fitzgerald, Travenol Laboratories, Round Lake, IL. Consultation on traceable dosimetry methods to achieve quality assurance in the radiation sterilization of medical devices.

R. B. Schwartz provided consultation and advice to members of the faculty of the U.S. Naval Academy on setting up a tissue-equivalent proportional counter system.

R. B. Schwartz tested and calibrated proton recoil counters for Dr. Chartier of the Centre d' Etudes Nucleaires, Fontenay-Aux-Roses, France.

R. B. Schwartz provided calibration and quality control irradiations for the Naval Surface Weapons Center area monitors.

R. B. Schwartz provided advice to Dr. Joseph Shonka of Atlan-Tech, Inc., on setting up a D_2O-moderated Cf source for doing quality assurance measurements on dosimetry for nuclear power plants.

R. B. Schwartz provided consultation and neutron beam irradiation to Battelle Pacific Northwest Laboratory for developing a remmeter based on a tissue equivalent proportional counter.

R. B. Schwartz provided consultation and neutron irradiation service for Prof. Robert Apfel of Yale University to assist in the development of a novel type of neutron personnel dosimeter.

R. B. Schwartz participated in a neutron dosimetry intercomparison with Battelle Pacific Northwest Laboratory and Lawrence Livermore National Laboratory.

Stephen M. Seltzer provided consultation and collaboration on electron transport techniques with members of the Spanish Junta de Energia Nuclear in support of a joint effort between NBS and Spain to develop general and accurate methods for the measurement of radioactivity of a radionuclide in a scintillating liquid.

Stephen M. Seltzer provided consultation to the National Physical Laboratory (England) on calculations of energy spectra and transmission curves of high-energy photon beams from the NPL Linac used for x-ray beam calculations.

Stephen M. Seltzer advised staff members at British Aerospace (England) and Alcatel Espace (France) on space-shielding calculations.

Stephen M. Seltzer provided electron and positron stopping powers, ranges and radiation yields to the Physikalisch-Technische Bundesanstalt (Germany) for use in PTB's beta-source calibrations.

Stephen M. Seltzer provided consultation on Monte Carlo modeling for electron/photon transport calculations to staff members of Los Alamos National Laboratory, Naval Surface Weapons Laboratory, and Sandia National Laboratories.

Stephen M. Seltzer provided consultation on x-ray fluorescence calculations to staff at NASA's Goddard Space Flight Center.

JOURNAL EDITORSHIPS

Division 536, Ionizing Radiation

B. M. Coursey, Editor, International Journal of Radiation Applications and Instrumentation, Part A. Applied Radiation and Isotopes.

B. M. Coursey, Editor, International Journal of Radiation Applications and Instrumentation, Part B. Nuclear Medicine and Biology.

W. B. Mann, Editor-in-Chief for North America, International Journal of Radiation Applications and Instrumentation, Part A. Applied Radiation and Isotopes.

W. B. Mann, Editor-in-Chief for North America International Journal of Radiation Applications and Instrumentation, Part B. Nuclear Medicine and Biology.

W. L. McLaughlin, Editor, International Journal of Applied Radiation and Isotopes.

W. L. McLaughlin, Editor, International Journal of Radiation Applications and Instrumentation, Part A. Applied Radiation and Isotopes.

W. L. McLaughlin, Editor, International Journal of Radiation Applications and Instrumentation, Part C. Radiation Physics and Chemistry.

W. L. McLaughlin, Editoral Board, Radiation Physics and Chemistry.

J. W. Motz, Editor, Computerized Radiology.

M. G. Simic, International Editorial Board, Free Radicals in Biology and Medicine.

TRIPS SPONSORED BY OTHERS

Division 536, Ionizing Radiation

Berger, M. J., sponsored by the International Atomic Energy Agency traveled to Rijswijk, The Netherlands to participate in an Advisory Group Meeting on Nuclear and Atomic Data for Radiotherapy and Radiobiology (September 16-20, 1985).

R. S. Caswell, sponsored by Columbia University, traveled to Irvington, New York to attend meeting of the Scientific Advisory Committee to the Radiological Research Accelerator Facility (RARAF) (January 27, 1986).

R. S. Caswell, sponsored by the International Atomic Energy Agency traveled to Dubrovnik, Yugoslavia to attend International Conference on Fast Neutron Physics and present invited paper (May 25-June 1, 1986).

R. S. Caswell, sponsored by the Kernforschungsanlage Juelich GMBH, traveled to the Institut fur Medizin, Julich, West Germany to present an invited lecture (June 2-4, 1986).

R. S. Caswell, sponsored by the Commission of European Communities, traveled to the Bureau Central de Mesures Nucleaires, Geel, Belgium, to present an invited lecture (June 11, 1986).

R. S. Caswell, sponsored by the International Commission on Radiation Units and Measurements, traveled to Bad Honnef, West Germany to attend the annual meeting (September 5-13, 1986).

B. M. Coursey gave an invited talk at Beckman Instruments, Fullerton, California, with the host organization covering all expenses (April 17, 1986).

B. M. Coursey attended the Editorial Board Meeting of the International Journal of Applied Radiation Isotopes, Oxford, England. Air travel and living expenses were provided by Pergamon Press, Oxford, England (June 5-6, 1986).

B. M. Coursey visited NEN Products/Dupont at the request of USFDA and DuPont in order to audit distribution of secondary standards of ^{201}Tl radiopharmaceuticals as part of a measurements assurance exercise, N. Billerica, Massachusetts. Expenses were covered by DuPont (July 27-28, 1986).

J. J. Coyne, sponsored by the International Atomic Energy Agency, traveled to Rijswijk, The Netherlands to participate in an Advisory Group Meeting on Nuclear and Atomic Data for Radiotherapy and Radiobiology (September 16-20, 1985).

Division 536, Trips Sponsored by Others (cont'd.)

M. Dizdaroglu, sponsored by Lawrence Berkeley Laboratory, Berkeley, CA, gave two invited talks and discussed recent developments in the field of radiation chemistry of DNA at Berkeley (July 1986).

D. D. Hoppes lectured and held laboratory discussions in the Peoples Republic of China at the Institute of Atomic Energy, Shaanxi Provincial Research Institute for Preventive Medicine, Sichuan University, and the National Institute of Metrology. The host organizations covered all living expenses (October 1985).

J. H. Hubbell traveled to Zagreb, Yugoslavia to present invited talk, "Radiation Physics Programs at the NBS," at the Rudjer Boskovic Institute. Subsistence expenses were provided by the Institute (October 10, 1985).

J. M. R. Hutchinson traveled to Rio de Janeiro to work with the Instituto de Radioprotecao E Dosimetria on a joint project for measuring low-level environmental materials using direct gamma-ray counting and activation analysis was covered by the host organization (September 15-October 4, 1985).

K. G. W. Inn participated in meetings to evaluate the state-of-the-art of bioassay as a measure of radiation exposure with emphasis on time and dose factors. He participated in the following meetings with the Oak Ridge Associated Universities covering all expenses:

DOE Radiobioassy and Internal Dosimetry Workshop, Albuquerque, NM (January 20-22, 1986).

First task group meeting of the Oak Ridge Associated Universities for the National Cancer Institute, Albuquerque, NM (February 10-11, 1986).

Task group meeting for the National Cancer Institute, Oak Ridge Associated Universities Facilities, Oak Ridge, TN (April 8-10, 1986).

Trach Etch Analyser evaluation meeting for the National Cancer Institute, Brookhaven National Laboratory, NY (July 29-30, 1986).

Task group meeting for the National Cancer Institute, Albuquerque, NM (September 15-18, 1986).

R. G. Johnson, sponsored by the International Atomic Energy Agency, traveled to Leningrad, USSR to present an invited paper and to participate in an Advisory Group Meeting on Neutron Source Properties (June 9-13, 1986).

R. G. Johnson, sponsored by Rutherford Appleton Laboratory, traveled to Didcot, UK to give a talk, "Detectors for Neutron Scattering in the eV Region (June 18, 1986).

L. Karam, fellowship sponsored by the Imperial Cancer Research Fund, London, UK. (June-Sept. 1986).

R. Loevinger traveled to Vienna, Austria to serve as consultant to the Dosimetry Group of the International Atomic Energy Agency at a meeting of the Scientific Committee of the Secondary Standard Dosimetry Laboratory Network. The trip was paid for by the IAEA (May 12-16, 1986).

W. L. McLaughlin, sponsored by FMC Corp., Santa Clara, CA, to give an invited talk on food irradiation technology to the staff of FMC Corp. (September 1985).

W. L. McLaughlin, sponsored by IAEA to conduct an international dosimetry and calorimetry intercomparison at Riso National Laboratory, Denmark, Harwell, UK, and National Physical Laboratory, Teddington, UK (October 1985).

W. L. McLaughlin, sponsored by IOTECH, Inc. to perform commissioning and QA dosimetry in a new radiation sterilization plant in Northglen, CO. (October 1985).

W. L. McLaughlin, sponsored by IAEA to attend advisory panel meeting at the IAEA, Vienna, Austria (February 1986).

W. L. McLaughlin, sponsored by IAEA to conduct dosimetry training food irradiation technology at the Office of Atomic Energy for Peace, Bangkok, Thailand (February-March 1986).

W. L. McLaughlin, sponsored by IAEA to give an invited lecture on dosimetry for food processing by ionizing radiation at Food Irradiation Section, IAEA, Vienna (March 1986).

W. L. McLaughlin, sponsored by AERE, Harwell, to conduct international dosimetry intercomparison and give lecture on telemetering dosimetry (May 1986).

W. L. McLaughlin, sponsored by Pergamon Press Publishers, to attend Editorial Meetings at Oxford, England (June 1986).

R. B. Schwartz, sponsored by the International Commission on Radiation Units and Measurements (ICRU), traveled to Paris, France, to attend first meeting of ICRU Report Committee on Measurement of Dose Equivalent (September 15-16, 1986).

S. M. Seltzer organized and chaired two invited/contributed sessions, "Charged-Particle Transport Calculations: Methods and Applications, I and II," at the Annual Meeting of the American Nuclear Society, Reno, Nevada (June 15-20, 1986).

Division 536, Trips Sponsored by Others (cont'd.)

M. G. Simic, sponsored by the University of Texas, Austin, TX, gave talk "The Chemistry of Irradiated Foods" (February 21, 1986).

M. G. Simic, sponsored by the Swiss Institute for Experimental Cancer Research, Lausanne, Switzerland, gave a talk, "Mechanisms of Free Radical Damage to DNA and Chemical Repair" (March 3, 1986).

M. G. Simic, sponsored by the World Health Organization, Lyon Cedex, France, "Mechanisms of Free Radical DNA Damage Implications for Risk Assessment" (March 4, 1986).

M. G. Simic, sponsored by Max Planck Institut für Strahlenchemie, Mülheim, West Germany, gave talk, "Reduced Reactivity of Resonance Stabilized Free Radicals Towards Oxygen (March 7, 1986).

M. G. Simic, sponsored by New York University Medical Center, New York, NY, gave a talk, "Mechanisms of Radiation Damage to DNA and Risk Assessment" (March 12, 1986).

M. G. Simic, sponsored by The University of Akron, Akron, OH, gave a talk, "Antioxidants" (April 1, 1986).

M. G. Simic, sponsored by Ruder Boskovic Institute, Zagreb, Yugoslavia, gave a talk, "Mechanisms of DNA Damage and Repair" (June 2, 1986)

M. G. Simic, sponsored by Institut für Strahlenhygiene, Oga, Neuherberg, Germany, gave a talk, "Possible Approaches in Post-Irradiation Dosimetry of Meats" (June 3, 1986).

M. G. Simic, sponsored by Belgrade University, Belgrade, Yugoslavia, gave a talk, "Mechanisms of Autoxidation and Antioxidants"(June 11, 1986).

M. G. Simic, sponsored by Case Western University, gave a talk, "Discrimination Between Direct and Indirect Effects of Radiation (August 8, 1986)

O. A. Wasson, sponsored by the Technical University of Dresden, traveled to Gaussig, German Democratic Republic to present an invited paper and deliver a conference summary at the XVth International Symposium on Nuclear Physics-Nuclear Fission (November 11-15, 1985).

STANDARD REFERENCE MATERIALS

Division 536, Ionizing Radiation

Radioactivity Group Standards Issued - 1 August 1985 through 31 July 1986

SRM	Radionuclide	Principal Use
4417L-E	Indium-111	Calibration of instruments for activity measurements of radiopharmaceuticals
4410H-K	Technetium-99m	"
4423L	Strontium-90-Yttrium-90	"
4407J	Iodine-125	"
4401L-L	Iodine-131	"
4412L-K	Molybdenum-99	"
4415L-J	Xenon-133	"
4416-G	Gallium-67	"
4404L-I	Thallium-201	"
4400L-H	Chromium-51	"
4940C	Promethium-147 solution	For use in calibrating instruments for measurement of this nuclide in reactor waste samples
4928C	Sulfur-35 solution	in vitro nuclear medicine
4932F	Mercury-203 solution	calibration of Ge(Li) and NaI(Tℓ) gamma-ray detectors
4904G	Americium-241 point source	calibration of alpha-particle detectors
4940	Plutonium-241 solution	beta particle standard for mixed plutonium assays
4267	Niobium-93m	x-ray standard for neutron dosimetry
4926C	Hydrogen-3 solution	calibration of liquid-scintillation counters
4332B	Americium-243 solution	for calibration of alpha-particle detectors for use in nuclear fuel cycle assays

CALIBRATION SERVICES PERFORMED

Division 536, Ionizing Radiation

I. Neutron Dosimetry Group

Type of Service	Customer	SP 250	No. of Tests
Certified Fluence Standards	Univ. of Arizona	8.1R	1
	AFRRI	8.1R	6
	AFRRI	8.1Q	1
		Total	8
Neutron Personnel Protection Instrumentation	Calvert Cliffs	8.1J	21
	Carolina P&L	8.1J	4
	Univ. of Wisconsin	8.1H	3
	Arkansas P&L	8.1J	2
	U. S. Air Force	8.1J	1
	Omaha Public Power	8.1J	1
	U. S. Army	8.1J	12
	Illinois Power	8.1J	4
	WPPSS	8.1J	2
	Barlett Nuclear Corp.	8.1J	1
	Eberline Instr. Corp.	8.1J	2
		Total	52
Neutron Source Calibration	Naval Surface Weapons Lab	8.1A	1
	Argonne Nat'l Lab	8.1A	1
	Alan Tech	8.1B	1
	Univ. of Arkansas	8.1B	1**
	U.S. Air Force, Newark	8.1A	1
		Total	5

*Covered under other agency contract

**Special 32-mg calibration, performed by NBS in the field relative to a 5-mg source calibrated in 1985

Division 536, Calibration Services Performed (cont'd.)

II. Radioactivity Group

August 1, 1985 to August 1, 1986

Category	Scheduled Calibrations(1) Number of Sources	Scheduled Calibrations(1) Total Fee $K	Non-scheduled Tests Number of Sources
Alpha-Particle Sources 8.2 H, I, J	30	25.4	8
Beta-Particle Point Sources and Gases (^{85}Kr) 8.2 P, Q, R	--	--	6
Gamma-ray Solutions, Point Sources, and Gases (^{133}Xe)	5	4.1	39
Mixed Radionuclide Sources, Solutions, Point sources and Gases(1)	--	--	16
Other Services	--	--	--
	35	29.5	69

Footnote

(1) Multiple sources under one Test Folder are counted as multiple calibrations. Replicate samples are not considered as separate sources. For example, Amersham submits 2 each of 3 different source forms. This is counted as 3 samples.

Division 536, Calibration Services Performed (cont'd.)

III. X-Ray Physics Group

Customer Classification	Type of Service	No. of Customers	No. of Tests Performed
Industrial:	A	26	155
medical product	B	8	35
sterilization	C	1	1
Industrial:	A	3	28
electronic hardness	B	6	74
testing	C	0	0
Industrial:	A	7	43
polymer	B	0	0
modification	C	4	5
National Laboratory:	A	0	0
electronic	B	2	78
hardness testing	C	0	0
Dept. of Defense:	A	1	22
electronic	B	0	0
hardness testing	C	0	0
Secondary	A	0	0
Calibration	B	1	10
Laboratory	C	0	0
University:	A	1	4
research	B	1	3
	C	0	0
Subtotals	A	38	252
	B	18	200
	C	5	6
Grand Totals		61	458

Service Code	Type of Service	SP 250 Number
A	Irradiate Dosimeters	49010S (8.6A)
B	Supply Transfer Dosimeters	49020S & 49030S (8.6B & 8.6C)
C	Special measurements	49050S (8.6F)

Division 536, Calibration Services Performed (cont'd.)

IV. Dosimetry Group and X-Ray Physics Group

Type of Service	Customer Type*	SP 250 Item No.	Number of Tests
Calibration of x-ray and γ-ray measuring instruments, and irradiation of TL dosimeters	1-7	46010-50	266
Calibration of γ-ray and β-particle sources	2-6	47010-40	24
Chemical dosimetry measurement assurance service for electron beam	2	48010-20	150
High-dose irradiation and interpretation	3-7	49010-50	408
Irradiat. of TLDs and prep. of units for shipboard measurement	Navy	N.A.	281
Instrument calibration and evaluation	5	N.A.	30
Totals			1160

*Column 2: 1, calibration labs; 2, hospitals; 3, nuclear energy establishments; 4, industry; 5, US government labs; 6, DoD labs; 7, universities.

SPONSORED SEMINARS AND COLLOQUIA

Division 536, Ionizing Radiation

John H. Barrett, National Physical Laboratory (NPL), Teddington, UK, "Dosimetry by Means of Aqueous Potassium Dichromate Solutions," September 24, 1985.

J. E. Burns, NPL, Teddington, U.K., "High-energy Dosimetry Program of the National Physical Laboratory", April 15, 1986.

Arne Miller, Risø National Laboratory, Roskilde, Denmark, "Calorimetry Standards for High Dose Radiation Measurements," November 21, 1985.

Z. P. Zagorski, Radiation Laboratory, University of Notre Dame, "Pulse Radiolysis Studies of Solid Hydrates," November 22, 1985.

Katsuhisa Kudo, Electro-technical Laboratory, Ibaraki, Japan, "Neutron Standards Measurements at the Electro-technical Laboratory," December 19, 1985.

S. T. Manson, Georgia State University, Atlanta, "Photoabsorption in the Soft X-Ray Range: The State of Our Knowledge," January 16, 1986.

J. Kosanetzky, Philips Research Laboratory, Hamburg, West Germany, "X-Ray Diffraction Computerized Tomography," January 31, 1986.

Marco Zaider, College of Physicians & Surgeons of Columbia University, New York, NY, "Reconciliation of Track Structure and Radiation Chemistry," March 13, 1986.

M. Quintiliani, Instituto Tecnologie Biomediche, Italy, "Radiation Chemistry of Glutathion," April 10, 1986.

Harry Ing, Chalk River Nuclear Labs, Ontario, Canada, "The Bubble-Damage Polymer Detector - A New Tool for Radiation Detection," April 17, 1986.

Alex Sevanian, University of Southern California, Los Angeles, CA, "The Cytotoxic and Mutagenic Properties of Cholesterol Oxidation Products," April 23, 1986.

Marc Desrosiers, Argonne National Laboratory, Argonne, IL, "Detection of Transient Organic Radical Cations Produced in Pulse Radiolysis. Time-Resolved Fluorescence Detected Magnetic Resonance," April 28, 1986.

K. H. Chadwick, Biology Division, European Economic Community, "Comparison of Ultraviolet and Ionizing Radiation Effects on Mammalian Cell Survival," May 12, 1986.

Jeff Stephens, The James Franck Institute, The University of Chicago, Chicago, IL, "Degradation of Slow Electrons in Molecular Gases," May 29, 1986.

M. P. R. Waligorski, Institute of Nuclear Physics, Krakow, Poland, "Particle Track Physics I. The Radial Distribution of Dose Around the Path of a Heavy Ion," and Particle Track Physics II, "Neoplastic Cell Transformation by Heavy Ions," June 25-26, 1986.

Jean Cadet, Centre d'Etudes Nucleaires de Grenoble, France, "Photo-and Radiation Chemistry of Purine Nucleosides," July 1, 1986.

Clemens von Sonntag, Max Planck Institut Fuer Strahzenchemie, West Germany, "Sulfur Radical Reactions Related to Radiation Protectors," July 10, 1986.

Emmanuel Riklis, Nuclear Research Center, Negev, Israel, "Biochemical Approach to Radiation Protection through DNA Repair," July 14, 1986.

Alex DeVolpi, Argonne National Laboratory, Argonne, IL, "Accidental-Coincidence Corrections," August 22, 1986.

D. J. Brenner, Columbia University School of Medicine, New York, "Nuclear Models and Neutron Data for Light Elements," August 28, 1986.

Alfred Frank Fuciarelli, Cross Cancer Institute, Edmonton, Alberta, Canada, "Detection and Modification of Radiation Damage in Nucleic Acids," September 22, 1986.

Krishan K. Sud, University of Jodhpur, Jodhpur, India, "Distorted-Wave Born-Approximation Pair Production Calculations in the Intermediate Energy Range," September 26, 1986.

TECHNICAL ACTIVITIES

Division 530.01 - Nuclear Physics

The Nuclear Physics Group conducts fundamental research in theoretical nuclear and particle physics, and experimental studies of intermediate energy electro- and photo-nuclear reactions. This activity is in support of the Center's role in carrying out research necessary for improved understanding of nuclear radiation processes and of the interaction of radiation and particles with matter. Theory activities are carried out by M. Danos, L.C. Maximon, S. Meshkov, and J.S. O'Connell, while experimental work is carried out by W.R. Dodge, E. Hayward, J.W. Lightbody Jr., and X.K. Maruyama. The experimental effort is currently focussed on experiments at the MIT/Bates and other laboratories, user activities and planning for CEBAF, as well as implementation of a beam line to do nuclear physics with the cw microtron now under construction at NBS by the Accelerator Research Group. Theoretical efforts include studies of coincidence electron scattering processes, Coulomb distortion and dispersive effects in electron scattering, neutrino reaction rates, quark gluon plasmas and related phenomena, and the spectroscopy of elementary particles using QCD. Approximately two-thirds of our theory effort is related to intermediate energy nuclear physics, the balance in high energy physics. This summary covers our activities during FY86.

The Nuclear Physics Group research program addresses priority questions in nuclear theory and experiment and, therefore, requires forefront facilities and a constant exchange of ideas and strong interplay with other laboratories and researchers in the field. The group is continuing with plans to develop a beam line for nuclear physics with the 200 MeV racetrack microtron (RTM). Research with this facility will be conducted by our own group as well as by outside users. Experiments with the linac have been phased out, except for calibration activities such as a recent experiment to determine the response of a stacked lead/scintillator total absorption counter to 50-100 MeV electrons. (This was done for a large external group involved in an approved Fermilab experiment.) In addition to planning a facility for electro-nuclear coincidence experiments, the group is participating in forefront electro- and photo-nuclear experiments using high energy accelerators at MIT and Mainz, and is involved in planning the next generation electron accelerator (CEBAF), aimed at exploring the QCD/nuclear physics interface. Strong user involvement at other labs, including MIT/Bates, CEBAF, and others, is considered an essential part of maintaining an active and balanced research program.

The NBS research program profits greatly from the participation of guest workers and collaborators (university faculty and graduate students), who extend our resources and bring in new ideas. This year many visitors and guest workers contributed to our programs. The list of scientific colleagues who have had extensive visits to NBS include:

Everett Fuller, retired NBS Nuclear Physics Group employee; Miles McCord from the Catholic University of America; Dennis Skopik from the University of Saskatchewan, Canada; Bent Schroder from the University of Lund, Sweden; Haaken Olsen from the University of Trondheim, Norway; Berndt Muller, University of Frankfurt, West Germany; Johann Rafelski, University of Cape Town, South Africa; Ray Lewis (and co-workers) from Pennsylvania State University; Jurgen Ahrens from the University of Mainz, West Germany; Reiner Schneider from the University of New Hampshire and the University of Mainz, West Germany; and Fred Gilman, SLAC. We encourage these involvements and, additionally, have an extensive seminar program which brings outside speakers to NBS.

In addition to guest worker scientists visiting NBS, a few members of the Nuclear Physics Group have had extensive stays at other nuclear laboratories: M. Danos, Centre d'Etudes Nucleaire de Saclay, France; Institute for Theoretical Physics, University of Frankfurt, West Germany; Institute of Theoretical Physics and Astrophysics, University of Cape Town, South Africa; L. Maximon, Centre d'Etudes Nucleaire de Saclay, France; J.S. O'Connell, Lewes Center for Physics (Lewes, DE); S. Meshkov, Aspen Center for Physics (Aspen, CO); Institute for Theoretical Physics of the University of California at Santa Barbara; E.Hayward, Oxford University Nuclear Physics Laboratory, England. These visits provide valuable new insights to our current research and often provide the perspective to plan and direct our future research activities. In the following sections we outline the groups primary research activities of the past year. This list includes research planning and development for the RTM, experimental activities at other laboratories, electromagnetic nuclear physics theory, nuclear theory, elementary particle physics, and miscellaneous activities.

Research Plans for the NBS/LANL RTM. The Nuclear Physics Group has submitted a proposal to the DoE for 450K$ in supplemental funding with which the necessary equipment for development of a nuclear physics beam line could be designed, constructed, and installed. The proposal received favorable reviews and recommendations for support, however, because of the lack of uncommitted FY86 funds, it could not be funded at this time. The proposal is currently being held by the DoE in an active status. We feel that researchers outside of NBS will also be interested in this facility, particularly while CEBAF is in its construction phase. We base this on the impressive efforts with modest energy cw electron facilities at the University of Mainz (180 MeV), the University of Illinois (100 MeV), and the University of Saskatchewan (300 MeV). The nuclear research groups at these institutions enjoy high priorities at their respective funding agencies for doing work which will now be addressable, in a cost effective way, with the NBS/LANL microtron as well.

At the present time we are converting the electrodisintegration spectrometer to an electron spectrometer. A new vacuum manifold has been fabricated to allow proper positioning of a vertical drift chamber in the focal plane. The VDC is presently under cnstruction at NBS. The printed circuit board was designed and layed out with an in-house CAD system and fabricated locally. Wires were put in and tensioned singly by hand. Centering accuracy is roughly the PC board milling accuracy (25 microns, non-accumulative) plus an additional 50 microns for positioning the wires within the centering holes. We have purchased amplifier/discriminator cards and TDCs from LeCroy and are planning a delay-line readout patterned after an Illinois design.

The spectrometer has a 5.6 msr solid angle and a 12 percent momentum acceptance. This spectrometer is a double focussing type (n=1/2 and beta=3/8), with a bend radius of 45.7 cm, a 120 degree bend angle, and D/M=1.9 cm/percent. The magnet has pole edges which are curved to reduce pole edge saturation effects and was designed to operate at central momenta up to 215 MeV/c. A single solid state telescope and a single high purity germanium detector are currently under development in-house for use in detecting hadronic reaction products in coincidence with scattered electrons. We expect that production experiments could best be done with an array of solid state detectors. Our proposal to DoE provides for a scattering chamber which could house such an array and provide rotation and gimbaling degrees of freedom.

We have reserved space for experiments not involving the magnetic spectrometer, such as work with a high flux bremsstrahlung beam. For such work a 45 degree dump magnet will be available in the switchyard area. Given the very high current capabilities of the microtron, 550 ua at 185 MeV, we can contemplate low cross section bremsstrahlung experiments, or polarization studies using off-axis bremsstrahlung and very thin radiators. A comparison of ^{2}H and ^{3}He photodisintegration, measuring polarization asymmetry as well as the full 3-body break-up of ^{3}He could provide an interesting test of our understanding of two-body processes in nuclei. Proton scintillator telescopes and a neutron detector would have to be developed for such an experiment to cover the full range of 3-body kinematics. Recalling that the quality of polarization measurements scales as the square of the polarization and linearly with intensity, with our higher beam intensity we are in a position to be competitive with polarization studies based on photon tagger set-ups. At present there are no plans for a photon tagging system such as at Illinois and Mainz, although space for such a device could be made available.

A good example of possible research with the RTM recently came out of Mainz. This work is in the area of giant resonances, in particular, studies of the E0, E1, and E2 resonances in 28_{Si}. Separated absorption strength energy profiles have been obtained for the different multipoles in the various possible decay channels. For the dipole resonance the resultant integrated strength is consistent, within rather large uncertainties, with either the Steinwedel-Jensen or the Goldhaber-Teller model. Hopefully, with more effort one could reduce these uncertainties to the point of discriminating between the various models, which in fact have rather dramatic differences in transition charge and current densities - SJ being more surface peaked, while GT is more of a bulk nuclear motion effect. We would pursue similar studies when the microtron comes on-line. As outlined in our proposal to the DoE, there are now detailed continuum shell model calculations for the giant E0, E1, and E2 resonances in ^{16}O with which to compare our data. The ^{12}C and ^{16}O systems, along with a heavier system for sake of comparison, would be the focus of our initial efforts with the microtron. We would extend the momentum transfers slightly beyond the Mainz limit.

External Activities. In addition to operating the microtron for nuclear research, however, we wish to continue our nuclear research activities external to NBS. We feel that a healthy balance should exist between our internal and external activities because a microtron based program is necessarily restricted in energy and in the type of physics we can address. We view such a facility as having a substantial window of opportunity for interesting nuclear physics, but most certainly, when CEBAF comes fully on-line, we will shift our emphasis to higher energy experiments. Even at this time, most of the NBS Nuclear Physics Group is engaged in activities at Bates and other major labs, and some are directly acting in support of CEBAF. In order to give some perspective to the extent of our external involvements it is appropriate at this point to inject a summary of our current experimental activities outside NBS.

We recently prepared and successfully defended a proposal to study the ^3He(gamma,2p) reaction using a cw bremsstrahlung beam at the Saskatchewan stretcher ring facility in Saskatoon. This work will be carried out using the 10 ua beam expected late this year. If successful, we could continue this work at NBS when the microtron beam becomes available. The goal of the experiment is to look for evidence of three-body effects in nuclear photodisintegration. Laget has estimated that without three-body effects the (gamma,2p) process should be down by two orders of magnitude from the (gamma,pn) process. By selecting kinematics that suppress the dominant one- and two-body dipole and quadrupole breakup amplitudes, we hope to get an estimate of the magnitude of three-body effects. We have chosen to look at kinematics where the final neutron lab energy is essentially zero and the two protons emerge opposed to each other near 90 degrees in the cm system. For these

kinematics there is no electric dipole moment in the final state; and, since the initial state is an s-state, there can be no E1 absorption strength. There is additionally no E2 absorption strength at 90 degrees, except by virtue of finite detector size, nor is there any M1 absorption strength by an s-state diproton system. Meson exchange effects are also highly suppressed in the diproton system. By choosing energies below pion threshold we have a kinematically complete experiment when the proton energies and angles are measured, even when a bremsstrahlung beam is used. Our plan is to use two plastic scintillator DE-E telescopes for this measurement, which should provide sufficient particle identification to separate 2- body and 3-body breakup processes. We feel that the additional use of polarized gammas from off-axis bremsstrahlung may provide an extra handle on the nature of any background processes related to the dominant quasideuteron absorption process. Collaborating in this experiment with the NBS group are researchers from the University of Saskatchewan, the University of Regina, and the University of Lund.
(J.W. Lightbody and J.S. O'Connell).

Recently, another area of investigation has arisen which has drawn our attention, namely the search for axions. According to Pecci and Quinn, fundamental CP invariance in strong interactions arises by coupling of fermion fields to an assumed scalar or pseudoscalar field. Axions are the quanta of this field, and the search for such particles is currently a very important and active area. Recently Tsai proposed that axion bremsstrahlung in electron scattering may be an important process in which to search for evidence for these particles. Several members of our Nuclear Physics Group are examining the details for such an experiment based on a cw electron beam, in which axion decay into an electron-positron pair with a characteristic energy spectrum is the signature. Maximal sensitivity appears to occur for electrons with energies just below the threshold for neutral pion production, or about 130 MeV. A good emittance beam delivering 50 ua is required, and the cw characteristic should allow clean detection of the electron-positron pair in coincidence, possibly with a pair spectrometer. The key to this experiment is to magnetically dump the beam immediately following the target, and then provide sufficient absorber to contain the electromagnetic shower and still allow the axion to escape before it decays. Limits on the axion lifetime and coupling constant can therefore be obtained. A proposal by members of the NBS group is being prepared in collaboration with H. Olsen of the University of Trondheim, and will be submitted to the appropriate facilities.
(W.R. Dodge, E. Hayward, and X.K. Maruyama)

In another recent development, members of our group are collaborating with H. Weller and M. Whitton of Duke University in an experiment to study the D-state in ^{4}He. This experiment uses the beam of polarized

deuterons provided by the 88" Berkeley cyclotron. These particles are captured by the deuterons in a CD_2 target and the ground-state capture gamma rays are detected over an angular range extending from 45 to 135 degrees. NBS has provided one of the two detector systems used in this experiment. This data are now being analyzed.
(W.R. Dodge and E. Hayward).

As we phased out our work on the NBS Electron Linac, our work at the MIT/Bates laboratory has increased greatly over the past several years. The list of currently active experiments in which we are involved, or those in final stages of analysis include:

(1) $^{238}U(e,e'f)$ in the delta resonance region,
(2) $^{52}Cr(e,e')$ 180 degree scattering,
(3) $^{3}H,^{3}He(e,e')$,
(4) (e,e'p) quasielastic studies using polarized electrons,
(5) (e,e'p),(e,e'alpha) giant resonance decay,
(6) (e,e'p) quasielastic studies of attenuation lengths,
(7) (e,e'p) quasielastic studies of current operators,
(8) transition radiation studies.

The $^{238}U(e,e'f)$ work is in collaboration with the University of Lund and University of New Hampshire nuclear physics groups. Preliminary data have been taken. When the fission data are integrated to give the partial contribution to the inclusive results we obtain a rather flat spectrum in energy loss. This is in contrast to the result expected on the basis of arguments that all knockout and delta processes at this energy loss should lead to fission. Apparently in the quasielastic scattering process at this momentum transfer there is insufficient residual interaction to induce fission. However, in the delta region we appear to arrive at the full inclusive cross section, consistent with the delta damping strongly into many-body channels, and thus providing the residual energy required to induce fission. More data will be taken during the next running cycle at Bates, including data on ^{233}U. (W.R. Dodge, J.W. Lightbody, J.S. O'Connell, X.K. Maruyama).

The $^{52}Cr(e,e')$ 180 degree scattering experiment to study properties of the first 2+ state transverse form factor is in final stages of analysis. These data have been taken in collaboration with J. Flanz of MIT and R. Lindgren of the University of Virginia. Data have been taken at momentum transfers between 0.5 and 1.2 fm^{-1}. The preliminary results have been compared with shell model calculations by R. Mooy of Drexel University, and also with a result obtained from the measured longitudinal form factor using the continuity equation to relate the transverse and longitudinal form factors. The shell model results use effective charges of 2.16e for protons and 1.16e for neutrons. Both the shell model and phenomenological model fail to predict sufficient transverse strength. DWBA calculations are planned. (J.W. Lightbody and X.K. Maruyama).

The ^{3}H,^{3}He(e,e') experiment is a collaboration involving many of the Bates users, too numerous to mention here. The target was a cooled gas system developed at Bates, and was operated near 45 K. at a pressure of approximately 220 psia. Data were taken at electron beam energies between 100 and 815 MeV, and for scattering angles between 54 and 134 degrees. The data are being analyzed at Bates and at UVA. The primary results will be improved radii determinations, threshold measurements to compare with breakup calculations, quasielastic measurements, and measurement of the delta production cross section. Together with earlier measurements on the deuteron and recent Saclay data on ^{3}H, these data should provide a data base with which stringent tests of few-body calculations can be made. (W.R. Dodge, J.W. Lightbody, and X.K. Maruyama).

A proposed (e,e'p) experiment to measure the polarization-related, fifth structure function in the quasielastic region was deferred until detector development could be made and a reliable polarized electron beam was available. Work is continuing to develop large area, high-purity Ge detectors, and to see if such detectors can be made to operate in the Bates beam environment. Directors reserve beam time at Bates will be used in the fall for this effort. Protons of 135 MeV kinetic energy will be detected at backwards angles in the Ge detectors, and electron coincidences will be sought in the ELSSY spectrometer. Recirculator energies will be required. Calculations in support of this experiment have been performed by VanOrden of the University of Maryland using a relativistic potential model. (W.R. Dodge and J.S. O'Connell).

In collaboration with the University of Maryland, the University of New Hampshire, Stanford, and MIT we are determining the feasibility of measuring the (e,e'p) and (e,e'alpha) cross sections for ^{12}C and ^{16}O in the GDR excitation region. Initial studies made two years ago seemed encouraging, but runs made in May 1985 indicated severe beam halo problems. Progress in reducing the beam halo has been made recently by observing the beam on a series of ZnS screens with holes in the center through which the most intense part of the beam could pass. The most recent tests indicate that the proposed experiments may indeed be possible at Bates. (W.R. Dodge).

The A-dependence of the ratio of (e,e'p) coincidence to (e,e') events was measured in July of this year to determine the macroscopic attenuation of 140 MeV nucleons. This was a collaborative study involving Argonne National Laboratory, Northwestern University, MIT, the University of Maryland, Mount Holyoke College, and NBS. The OHIPS spectrometer was used to detect 600 MeV/c electrons in coincidence with 400 to 600 MeV/c protons detected in the BIGBITE spectrometer. The data from this experiment are presently under analysis and should provide information on proton propogation in nuclei which is essential for the analysis of many processes, including pion absorption and inclusive proton induced reactions. (X.K. Maruyama).

In collaboration with the University of Maryland, the University of New Hampshire, and MIT we are attempting to measure the density dependence of the electromagnetic current operators by comparing the q-dependence of the (e,e'p) cross sections in ^{12}C and ^{63}Cu at constant energy transfer, proton energy, and recoil momentum. The experiment was scheduled to run in June 1985, but because of linac problems data were only taken at one angle pair around the q-direction). Following an aborted attempt to run in June of this year, the experiment will be rescheduled for the fall. (W.R. Dodge).

In collaboration with M.A. Piestrup of Adelphi Technology, M.J. Moran of LLNL, and B.L. Berman of George Washington University, the use of transition radiation as a source of hard x-rays for applications is being investigated. A Bates experiment is planned for this fall to demonstrate that high fluxes of x-rays can be obtained from high average current electron beams at moderate energies. The goal of the preliminary experiment will be (1) to measure the absolute flux of x-rays from foil stacks of transition radiators, and (2) to destructively test these stacks over long periods of time. Potential applications for transition radiation include uses for angiography, x-ray lithography, beam diagnostics, and particle detection. (X.K. Maruyama)

In addition to the above active areas of investigation, we are preparing an expanded paper describing our earlier work (in collaboration with the University of Lund, MIT, and UNH) on the excitation of the delta resonance by forward angle electron scattering (J.S. O'Connell et al.,PRL53,1984.) The expanded work will contain the complete data set including data taken at 537 MeV as well as the 730 MeV data. Details of the data analysis and comparison to delta-hole model calculations by Koch and Ohtsuka will be presented. The delta-hole calculations were found to underestimate the measured cross sections in the resonance region by about 20 percent, but describe the shape rather well.
(W.R. Dodge, J.W. Lightbody, X.K. Maruyama, and J.S. O'Connell)

Electromagnetic Nuclear Theory Activities. In connection with the design of tagged photon systems, a detailed analysis of the fully differential cross section and polarization for bremsstrahlung has been carried out for small angles and high energies of the final electron and photon. In addition, simple, analytic closed form expressions have been developed for the angular distribution of the scattered electron (integrated over photon angles) including the effects of atomic screening. In addition to studies of bremsstrahlung, analysis of electron and positron scattering from nuclei is being carried out in collaboration with experimentalists at the University of Illinois and at the Division of High Energy Nuclear Physics, Saclay, France. Investigation has continued into the photo and pionic disintegration of few body systems (^2H, ^3H, ^3He), particularly in the region dominated by the isobar (200-400 MeV). The aim is the formulation of a relatively simple model for these reactions, for comparison with currently existing data, in particular, the recent experimental data on the radiative capture of polarized protons by deuterons. (L.C. Maximon)

In addition to the above investigations, work is going on in connection with the momentum transfer dependence of the quasi-elastic peak position observed in electron scattering. This effect, observed for ^{4}He and ^{12}C, can be related to the concept of effective mass and in turn to momentum dependence in the mean field experienced by the knock-out nucleon. This work is being carried out in collaboration with the University of Lund photo-nuclear group. In a collaboration with E. Dressler of Penn State, a calculation of the (e,e'Nπ) cross section is being carried out within the context of the Fermi gas model. This type of calculation will be useful for estimating counting rates for experiments planned for CEBAF and other cw electron beam facilities. The delta resonance is a composite pi-N system and dominates pion and photon reactions at intermediate energies. Its production, propogation, and subsequent decay into the pion-nucleon channel is therefore of great importance. In collaboration with T. Gaiser of the Bartol Research Foundation, work has continued on calculating the spectra of leptons generated by cosmic ray neutrinos. (J.S. O'Connell)

Finally, in connection with CEBAF planning, we are examining the prospects for studying the two-nucleon knockout reaction with the high energy beams planned for CEBAF. We are looking at the various known processes that contribute to this reaction, including final state effects, meson exchange currents, as well as initial state two-body correlations. We are also examining the processes that will form the experimental backgrounds to the two-nucleon knockout reaction. We have modeled the proton electro-production process including quasi-free knockout, delta production and decay, and quasi-deuteron breakup. We have also modeled the single arm electron scattering process in the quasi-free and delta production regions. Through these efforts we hope to find the sensitivity of the various measurable structure functions to the processes of interest, using this as a guide to plan measurements at CEBAF. (J.W. Lightbody and J.S. O'Connell)

During this year the problem of the polarizability of the nucleon has been addressed. This quantity is of fundamental importance relating to basic predictions of QCD, and plans are being drawn for the experimental study of both the electric and magnetic polarizability using the new generation cw electron machines. The photonuclear absorption cross section of the proton is dominated by the delta-resonance, a magnetic dipole state. This resonance overlaps an electric dipole continuum and is followed at higher energies by other pion-nucleon resonances of electric dipole and quadrupole character. It is difficult to reconcile what we know about the total photo-absorption cross section with the results of earlier and somewhat imprecise photon scattering experiments, which conclude that the electric polarizability is ten times the magnetic polarizability. The theoretical answer to this problem might lay in a proper treatment of retardation effects. Experimentally, the magnetic polarizability should be better determined. One possiblility is to use a linearly polarized photon beam and measure the scattering intensity along the polarization direction. (E. Hayward).

Nuclear Theory. The activities described in this section were carried out by M. Danos and co-workers. In the past, nuclear forces have been treated by computing a nucleon-nucleon 2-body force in terms of meson exchanges between point nucleons treated in second order perturbation, although it was realized that these nucleons were not point particles but in fact occupied a large part of the volume of nuclei. Now the origin of nuclear forces must be rethought in terms of the underlying quark structure. There are two aspects to this problem. First, the short range part of the interaction must be re-done in terms of explicit quark degrees of freedom. The model available for this treatment is the bag model. However, two-nucleon interactions in this model have six quarks in the bag, and if an exchanged meson is included then there are seven quarks and an anti-quark. There are many-body correlations among the quarks. A program to investigate these forces has been started.

To replace the ad hoc boundary conditions of the bag model by a correct description of the hadron vacuum interface in fact requires a solution, or at least a semi-quantitative understanding, of the confinement problem. In fact, it is nuclear physics which will have to yield information on the confinement effect. As a first step one must achieve an understanding , i.e., a description, of the vacuum itself before considering the interface. It is widely believed that the confinement in QCD, in analogy with superconductivity, results from the existence of a physical vacuum which is removed from the remainder of the spectrum by an energy gap, which exhibits a Meissner-Ochsenfeld effect, and which can not be described by perturbative quantum field theory. More particularly, it is believed that these characteristics of the physical vacuum result from the infrared properties of QCD. Utilizing these considerations, an attempt is underway to construct a model of the QCD vacuum with the techniques developed in the context of superconductivity theory.

The other aspect concerns the long-range part of the interaction, i.e., that part where the microscopic structure of the vertex is unimportant. There the many-body aspects of the system nucleon-plus-mesons have to be accounted for, which are neglected in the presently employed perturbation treatment of the nuclear force. This proper description requires that the nucleus be treated as a relativistic many-body system. A program of such a treatment is underway.

A new emerging field of nuclear physics concerns the question of explicit manifestations of QCD effects in nuclear reactions. A promising approach is the observation of a quark-gluon plasma in the high energy collision of two heavy nuclei. Diverse aspects of this subject are being explored.

An example of the importance of quarks in the nucleus is a recent study in which experiments at SLAC and CERN have been used to show that between 2 and 10 percent of the quark wave function occupies the nucleus as a whole rather than being correlated into individual nucleons. (M. Danos.)

Elementary Particle Theory. The elementary particle theory program under S. Meshkov is varied, with activity on several fronts. The ongoing QCD program was strengthened by an active participation in the Nuclear Chromodynamics Workshop at the Institute for Theoretical Physics (ITP) at the University of California, Santa Barbara. A comprehensive, up to date review of Glueballs and Meson Spectroscopy was prepared while at ITP and presented at the 1986 Aspen Winter Physics Conference. Stimulated by this review and interactions at ITP, Meshkov, Palmer, and Pinsky have examined recent data on the iota/E system to elucidate the quark/glue nature of this particle (or particles). In a recent paper, they find that a considerable simplification is achieved when the system is viewed as comprised of at least two states: a high mass iota around 1460-1500 MeV with JPC=0^{-+} and a low mass E around 1420 MeV with JPC=0^{-+} or 1^{++}. The iota has a considerable admixture of glue in its wave function and its quark content is near the electromagnetically "inert" mixture $u\bar{u}+d\bar{d}-5s\bar{s}$. A number of experimental tests are proposed which will shed light on this complex and interesting system.

A new area of research, the production of neutral vector meson pairs by photon-photon interactions, was started at ITP-UCSB in collaboration with S.J. Brodsky of SLAC. A crossing symmetric description of gamma-gamma production of neutral rho meson pairs and other vector meson pairs was formulated which describes both the energy dependence and the production angular dependence for these processes (in agreement with experiment) in terms of the Yennie shrinking photon method which successfully describes electroproduction. (S. Meshkov)

Miscellaneous Activities. During the past year members of our staff have participated extensively in outside activities. J.S. O'Connell has been chairman of the MIT/Bates User Group and has been heavily involved in planning and review matters associated with that lab. He has also delivered lectures at the European Intermediate Energy Nuclear Physics Summer School in Bochen, West Germany, helped organize the Three-Nucleon Conference held at George Washington University, and helped run the Lewes Center for Physics in Lewes, DE. J.W. Lightbody has been involved with the

CEBAF effort in an advisory role as well as in running the (e,e'2N) working group at the CEBAF Summer Workshop. He has delivered lectures at the NSF sponsored National Intermediate Energy Nuclear Physics Summer School held at Georgetown University and participated in the Program Advisory Committee activities of the Saskatchewan Linear Accelerator Laboratory. M. Danos has been heavily involved in a workshop on muon catalyzed fusion held at NBS. E. Hayward has been a member of the Executive Board of the American Physical Society, the SURA Board of Trustees, and the SURA Committee on Science and Technology. S. Meshkov has been heavily involved in running the Aspen Center for Physics in Aspen,CO. J.W. Lightbody and X.K. Maruyama have been involved in writing proposals, including developing background material, to other agencies for funding of new facilities. Every member of the group has given lectures at other institutions and participated heavily in user activities. The theorists of the group have, in addition to carrying out their own research, provided guidance and advice to the experimental members of the group whenever needed.

We feel that the Nuclear Physics program addresses the long range NBS goals in nuclear research, and there is a growing vitality from measured involvement with the larger nuclear research community. The theoretical efforts cover the full spectrum of current interest in nuclear research. The experimental effort represents a healthy balance between in-house research and research at other facilities.

SPONSORED WORKSHOPS, CONFERENCES AND SYMPOSIA

Division 530.01, Nuclear Physics Group

Meshkov, S., Nuclear Chromodynamics Workshop, Institute for Theoretical Physics, UCSB, September 2, 1985 - February 2, 1986.

Meshkov, S., Aspen Winter Physics Conference, January, 1986.

Meshkov, S., VIII International Workshop on Photon-Photon Collisions, April, 1986.

Meshkov, S., Aspen Center for Physics, June 23 - Sept. 15, 1986, including Superstring Workshop.

Meshkov, S., DPF Superconducting Supercollider Planning Meeting, Snowmass, CO., June 23 - July 11, 1986.

Meshkov, S., XXIII International Conference on High Energy Physics, Berkeley, CA, July 16 - July 23, 1986.

Meshkov, S., Keystone Center, Keystone, CO - National Advisory Committee on Future Funding of U.S. Science and Technology R & D, August 24-25, 1986.

INVITED TALKS

Division 530.01, Nuclear Physics Group

Danos, M., "Prospects of Muon Catalyzed Fusion", University of Maryland, December, 1985.

Danos, M., "The QCD Vacuum", Maratea, Italy, June, 1986.

Danos, M., "The QCD Vacuum", University of Bonn, Dept. of Physics, June, 1986.

Danos, M., "The QCD Vacuum", University of Basel, Dept. of Physics, June, 1986.

Dodge, W. R., "Early Results of the MIT-Bates ^3H and ^3He Experiment", University of Maryland, Physics Department, April 11, 1986.

Hayward, E., "Nuclear Photon Scattering" at the Nuclear Physics Laboratory, Oxford, England, November 12, 1985.

Hayward, E., "Photon Scattering Measurements" before the Nuclear Interactions Group of the U.K. in Edinburgh, Scotland, November 13, 1985.

Hayward, E., "Photon Scattering" at the University of Lund, Sweden, May 27, 1986.

Lightbody, J. W., Jr., "Deep Inelastic Electron Scattering", Memphis State University, Physics Department Colloquium, February 13, 1986.

Lightbody, J. W., Jr., "Experimental Aspects of Electron Scattering", Georgetown University, Washington, DC, National Summer School for Intermediate Energy Physics, sponsored by the NSF, June 12 and 13, 1986.

Lightbody, J. W., Jr., Introductory talk for the (e,e'2N) Work Group; Summary talk for the (e,e'2N) Working Group, CEBAF Summer Workshop, Newport News, VA, June 23-27, 1986.

Lightbody, J. W., Jr., "Modeling Electron and Proton Yields at Electron Accelerators", Lewes Center for Physics, Lewes, DE, July 14-25, 1986.

Lightbody, J. W., Jr.,"Interpretation of Quasi Elastic and Delta Resonance Electron Scattering Data In Terms of Modified Nucleon Charge Distributions", CEBAF Summer Study Group, July 10, 1986.

Maruyama, X. K., "Cerenkov Radiation", Saskatchewan Accelerator Laboratory, University of Saskatchewan, Saskatoon, Canada, October, 1985.

Maruyama, X. K., "Microwave Cerenkov Radiation", Nuclear Physics Seminar, Drexel University and University of Pennsylvania, Drexel University, Philadelphia, PA., June, 1986.

Maruyama, X. K., "Cerenkov Radiation as a Diffraction Phenomena", Bates Accelerator Laboratory Seminar, MIT, Middleton, MA, June 27, 1986.

Maruyama, X. K., "Non-Nuclear Photon Generation with Ultra-Relativistic Electrons", AERE, Harwell, England, August 30, 1986.

Maximon, L. C., "The Study of Coulomb and Dispersive Effects by the Comparison of Positron and Electron Scattering from Nuclei", Division of High Energy Nuclear Physics, CEN, Saclay, France, January 8, 1986.

Maximon, L. C., "Tagged Photons", Lewes Center for Physics", Lewes, Delaware, July 22, 1986.

Maximon, L. C., "Polarization Properties of Tagged Photons", Saskatoon Linear Accelerator Laboratory, Saskatoon, Saskatchewan, Canada, September 23, 1986.

Meshkov, S., Lecture Series on "Glueballs and Meson Spectroscopy", Nuclear Chromodynamics Workshop. Discussed work on stringlike behavior of Heavy Quarkonia in NCD Workshop. Institute for Theoretical Physics, Univ. of California, Santa Barbara, (USCB), September, October, November, 1985.

Meshkov, S., "Glueballs and Meson Spectroscopy", Elementary Particle Physics Seminar, U. C. Irvine, January, 1986.

Meshkov, S., "Glueballs and Meson Spectroscopy", Summary Talk, Aspen Winter Physics Conference, Aspen, CO, January 19, 1986.

Meshkov, S., "Glueballs and Meson Spectroscopy", Elementary Particle Seminar, Ohio State Univ., Columbus, Ohio, March, 1986.

Meshkov, S., "Applications of Amplitude Factorization to $\gamma\gamma$ Production of Vector Meson Pairs", VII International Workshop on Photon-Photon Collisions, College de France, Paris, France, April, 1986.

Meshkov, S., "Implications of the $\gamma\gamma$ and $\gamma\rho$ Decays of the Iota", VII International Workshop on Photon-Photon Collisions, College de France, Paris, France, April, 1986.

Meshkov, S., "Report on Nuclear Chromodynamics Workshop at ITP-UCSB", Center for Radiation Research Seminar, NBS, March, 1986.

Meshkov, S., "Glueballs", Colloquium, Brookhaven National Laboratory, Upton, NY, May, 1986.

O'Connell, J. S., "Nuclear Electromagnetic Response in the Delta Region", University of Georgia, Athens, GA, December 2, 1985.

O'Connell, J. S., "Neutrino Reactions", University of Saskatchewan, Saskatoon, Canada, February 10, 1986.

O'Connell, J. S., "CW Bremsstrahlung Reactions", Lake Louise, CAP Meeting, Canada, February 12, 1986.

O'Connell, J. S , "Nuclear Electromagnetic Response in the Delta Region", University of Saskatchewan, Saskatoon, Canada, February 14, 1986.

O'Connell, J. S., "What's New in Cosmic Rays", George Washington University, Washington, DC, March 6, 1986.

O'Connell, J. S., "Photodisintegration of Helium-3 and the Three Nucleon Force", George Washington University, Washington, DC, April 25, 1986.

O'Connell, J. S., "Atmospheric Neutrinos", APS Meeting, Washington, DC, May 1, 1986.

O'Connell, J. S., "Momentum Dependence of the Nucleon's Effective Mass", Center for Physics, Lewes, DE, July 8, 1986.

O'Connell, J.S., "How to Make a Coincidence Measurement", Bosen, West Germany Summer School, September 2, 1986.

O'Connell, J. S., "Deep Inelastic Electron Scattering", University of Mainz, West Germany, September 10, 1986.

PUBLICATIONS

Division 530.01, Nuclear Physics Group

Buskirk, F.R., J.R. Neighbours and X.K. Maruyama, Radiation Produced by the Modulated Electron Beam of a Free Electron Laser, Naval Postgraduate School, Monterey, California, Report NPS-61-86-013 (1986).
Danos, M., Irreducible Density Matrices, NBSIR 85-3270 (1985).

Danos, M. and A. Johnson, Quarks in the Nuclear Ground State, J. Phys. G. 12, L13 (1986).

Gaisser, T. K. and J. S. O'Connell, Interactions of Atmospheric Neutrinos in Nuclei at Low Energy, Physical Review D34, 822 (1986).

Dodge, W. R., E. Hayward, M. N. Martins, and E. Wolynec, (e,p) and e,α) reactions in ^{90}Zr, Phys. Rev. C32, 781 (1985).

Dodge, W. R., An estimate of the proton yield from quasi-elastic scattering on ^{16}O at an incident electron energy of 800 MeV, in the Proc. of XIth Europhysics Divisional Conference on Nuclear Physics with Electromagnetic Probes, edited by S. Methfessel, Bochum, July 1985).

Dodge, W. R. and E. Hayward, Siegert's Theorem and Nuclear Electrodisintegration, Phys. Rev. C33, 1251 (1986).

Electrodisintegration Experiments and Virtual Photon Spectra in Proceedings of the Fifth Course of the International School of Intermediate Energy Nuclear Physics, edited by R. Bergere, S. Costa, and C. Schaef (World Scientific Publishing Co., Singapore, 1986) p. 132.

Fishbane, P.M., P. Kaus and S. Meshkov, Do Heavy Quarkonia have Stringlike Behavior?, Phys. Rev. D., 33, 852 (1986).

Kohmura, T., T. Suzuki, M. Cauvin, V. Gillet, and M. Danos, Shell Model Interaction Energies in a Relativistic Hamiltonian Formulation, Part I; Nucl. Phys. (1985).

Lightbody, J. W., Jr., Summary (e,e'2N) Working Group, CEBAF Summer Workshop, Newport News, VA, June 23-27, 1986.

Martins, M. N., E. Hayward, G. Lamaze, X. K. Maruyama, F. J. Schima and E. Wolkynec, Experimental Test of the Bremsstrahlung Spectrum, ;Proceedings of the Conference on Nuclear Physics with Electromagnetic Probes, XIth Europhysical Divisioanl Conference, Paris, 188 (1985).

Neighbors J. R. and X. K. Maruyama, Onset of Cerenkov Radiation, Proc. Annual SDIO/DARPA/Services Propagation Review (1985).

Division 530, Publications (cont'd)

Neighbors, J. R.,F. R. Buskirk, and X. K. Maruyama, Emmission Threshold for Cerenkov Radiation, Naval Postgraduate School, Monterey, California, Report NPS-61-85-005, (1985).

Maruyama, X. K., J. R. Neighbours and F. R. Buskirk, Electron Beam Bunch Profile Determination through Cerenkov Radiation, IEEE Transactions on Nuclear Science, 32, 1994 (1985).

Maruyama, X. K., J. R. Neighbours, F. R. Buskirk, D. D. Snyder, M. Vujaklija, and R. G. Bruce, Observation of Microwave Cerenkov Radiation as a Diffraction Pattern, J. Appl. Phys. 60, 518 (1986).

Maruyama, X.K., F. R. Buskirk, J. R. Neighbours, R. D. Fitzpatrick, P. F. Cromar and J. E. Mark, Study of Off-Axis Radiation Energy Deposition from 10 MeV Electrons Traversing Through Water, Liquid Nitrogen and Air, Naval Postgraduate School, Monterey, California, Report NPS-61-86-001, (1986).

Maruyama, X. K., F. R. Bukskirk, J. R. Neighbours, Microwave Cerenkov Radiation as a Diffraction Phenomenon, submitted to the Proceedings of the Conference on the Application of Accelerators in Research and Industry (to be published in Nuclear Instruments and Methods (1987)).

Cha-mei Tang, P. Sprangle, S. Penner, X. K. Maruyama, Proposal for FEL Experiment Driven by the National Bureau of Standards's CW Microtron, Proceedings of the 8th International Free Electron Laser Conference, Glasgow (1986) (to be published in Nuclear Instruments and Methods (1987)).

PUBLICATIONS IN PREPARATION

Division 530.01, Nuclear Physics Group

Brodsky, S. J. and S. Meshkov, "Application of Amplitude Factorization to $\gamma\gamma$ Production of Vector Mesons Pairs", (to be submitted to Phys. Rev. Letters).

Buskirk, F. R., J. R. Neighbours and X. K. Maruyama, Radiation Produced by the Modulated Electron Beam of a Free Electron Laser, Proceedings of the 8th International Free Electron Laser Conference, Glasgow (1986) (to be published in Nuclear Instruments and Methods (1987)).

Dodge, William R., Diffraction virtual photon spectra partitioned according to the four structure functions of the (e,e'X) cross section for all electric and magnetic multipoles in the long wave limit. To be submitted to the Proceedings of the Conference of the Application of Accelerators in Research and Industry at Denton, Texas, November 10-12, 1986, and to the Physical Review.

J. Flanz and J. W. Lightbody, Jr., 180°- Electron Scattering from the 2^+ State in ^{52}Cr.

L. S. Cardman, S. P. Fivozinsky, J. W. Lightbody, Jr., X. K. Maruyama, S. Penner, P. Trower, S. Williamson, Elastic Electron Scattering from ^{12}C.

Maximon, L. C., Physics Reports "Tagged Photons" (in press).

Meshkov, S., "Glueballs and Meson Spectroscopy" (Proceedings of Aspen Winter Conference, 1986).

Meshkov, S., W. F. Palmer and S. S. Pinsky, "The L/E System", submitted to Physical Review Letters.

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Schroder, B. and J. S. O'Connell, Momentum Dependence of the Nucleon Effective Mass as Measured in Quasi-Free Electron Scattering.

TECHNICAL AND PROFESSIONAL COMMITTEE PARTICIPATION AND LEADERSHIP

Division 530.01, Nuclear Physics Group

Hayward, E. V., Executive committee of the Division of Nuclear Physics of the American Physical Society.

Hayward, E. V., SURA Borad of Trustees.

Hayward, E. V., Science and Technology Committee of SURA.

Lightbody, J. W., Jr., Member, Program Advisory Committee, Saskatchewan Accelerator Laboratory, Saskatoon, Saskatchewan, Canada.

Lightbody, J. W., Jr., Member, National Advisory Board, CEBAF, Newport News, VA.

Lightbody, J. W., Jr., Member, Technical Advisory Committee, MIT/Bates Linear Accelerator.

Lightbody, J. W., Jr., Member, Board of Directors of the CEBAF User Group.

Lightbody, J. W., Jr., Chairman-Elect, CEBAF User Group.

Maruyama, X. K., Member, Minority Advisory Committee, National Measurement Laboratory, National Bureau of Standards.

Meshkov, S., Member, Advisory Board, Aspen Center for Physics, Aspen, Co.

Meshkov, S., Member, Organizing Committee for Winter Conference, Aspen Center for Physics, Aspen, CO.

Meshkov, S., Chairman, 1987 Program Committee, Aspen Center for Physics, Aspen, CO.

Meshkov, S., Chairman, 1986 Colloquium Committee, Aspen Center for Physics, Aspen, CO.

Meshkov, S., Member, Interagency Seminar Series (Wash).

Meshkov, S., Member, Fermilab - organizing committee for Fermilab Low Energy Antiproton Facility Workshop.

Meshkov, S., Member, National Advisory Committee on Future Funding of U.S. Science and Technology R + D, Keystone Center, Keystone, CO.

Division 530, Technical and Professional Committee Participation and Leadership (cont'd)

Meshkov, Chaired Session on Hadron Physics at Washington, DC, APS Meeting, April, 1986.

O'Connell, J. S., National Bureau of Standards- Editorial Board, Research Advisory Committee.

O'Connell, J. S., American Physial Society- Nominating Committee, Division of Nuclear Physics and Editorial Advisory Board for Physical Review C.

O'Connell, J. S., Bates Linear Accelerator Center - Program Advisory Committee, Director's Advisory Board, Users Group-President.

O'Connell, J. S., Lewes Center for Physics - Governing Board.

TRIPS SPONSORED BY OTHERS

Division 530.01, Nuclear Physics Group

Danos, M., Centre d'Etudes Nucleaire de Saclay, France.

Danos, M., Institute of Theoretical Physics and Astrophysics, University of Cape Town, South Africa.

Danos, M., Institute for Theoretical Physics, University of Frankfurt, West Germany.

Danos, M., Los Alamos National Laboratory, Los Alamos, New Mexico.

Dodge, W. R., MIT/Bates Linear Accelerator, to participate in collaborative experiments, January 12-21, 1986; February 9-18, 1986; March 3-17, 1986; March 24-April 3, 1986.

Hayward, E. V., round-trip air fare to London, England sponsored by the Science and Engineering Research Council.

Hayward, E. V., Trip to Edinburgh, Scotland was sponsored by the U. K. Nuclear Interactions Groups.

Lightbody, J. W., Jr., Memphis State University, colloquium, February 13-14, 1986.

Lightbody, J. W., Jr., CEBAF Summer Workshop, Chaired Working Group, June 23-27, 1986.

Lightbody, J. W., Jr., University of Saskatchewan, Program Advisory Committee Meeting, Nov. 7-12, 1985.

Lightbody, J. W., Jr., MIT/Bates Accelerator Advisory Committee Meeting, September 12-13, 1985.

Lightbody, J. W., Jr., CEBAF National Advisory Board Meeting, September 12-13, 1985.

Lightbody, J. W., Jr., CEBAF National Advisory Board Meeting, January 10-11, 1986.

Lightbody, J. W., Jr., CEBAF National Advisory Board Meeting, September 18-19, 1986.

Lightbody, J. W., Jr., MIT/Bates Linear Accelerator to participate in collaborative experiments January 17-28, 1986; March 22-27, 1986.

Maruyama, X. K., Naval Postgraduate School, Monterey, California, to consult on energy deposition of relativistic electrons in matter, January, 1986. Trip sponsored by Naval Postgraduate School.

Maruyama, X. K., MIT/Bates to participate in the tritium/^{3}He electron scattering experiment. Trip sponsored by MIT. January, February, March, 1986.

Maruyama, X. K., University of Saskatchewan to present a talk. Sponsored by University of Saskatchewan, October, 1985.

Maruyama, X. K., Drexel University, Philadelphia, PA, to present talk sponsored by Drexel University, June, 1986.

Maruyama, X. K., Lawrence Livermore National Laboratory to participate in an experiment on transition radiation, July, 1986.

Maximon, L. C., trip to Center for Nuclear Studies, Saclay, to consult and work with experimentalist and continue collaboration on elastic and inelastic electron scattering, and the production of monoenergetic proton beams, at the Saclay Linear Accelerator, Saclay, France, December 20, 1985 to February 7, 1986.

Maximon, L. C., trip to Brookhaven National Laboratory to consult with experimentalists and plan experiments on photon scattering, September 10-12, 1986.

Maximon, L. C., trip to Saskatoon Linear Accelerator Laboratory, Saskatoon, Saskatchewan, Canada, to consult with experimentalist and plan for the design of a photon tagging system, September 23-30, 1986.

Meshkov, S., trip to Aspen Winter Conference to present invited summary talk, sponsored by UCSB, January, 1986.

Meshkov, S., trips to Ohio State University to present seminar and to work on collaborative research, sponsored by Ohio State University, March 17-31, 1986 and May 5-7, 1986.

Meshkov, S., trip to Brookhaven National Laboratory to present colloquium, sponsored by Brookhaven National Laboratory, May 19-21, 1986.

Meshkov, S., trip to present seminar at UC Irvine, sponsored by UCSB, January, 1986.

Meshkov, S., trip to participate on the National Advisory Committee on Future Funding of U. S. Science and Technology R & D at Keystone Center, Keystone, CO, sponsored by Keystone Center, August, 1986.

SPONSORED SEMINARS AND COLLOQUIA

Division 530.01, Nuclear Physics Group

Berman, Barry L., Department of Physics, George Washington University, "Coherent Transition Radiation", December 12, 1985.

Buskirk, J., Dept. of Physics, Naval Postgraduate School and Mack, Joseph, Los Alamos National Laboratory, "AF Cherenkov Radiation as a Beam Signature at Phermex", February 27, 1986.

Meshkov, S., Nuclear Chromodynamics Workshop, March 14, 1986.

Reiner Schneider-Rueck, Bates Linear Accelerator Center, "Coincidence Experiments in the Giant Resonance", April 1, 1986.

Leisi, H. J., Swiss Institute for Nuclear Research, "Muonic and Pionic X-Ray Experiments with Crystal Diffraction Spectrometry, May 15, 1986.

Gilman, Frederick, Stanford Linear Accelerator Center, "Search for Neutral Leptons", May 23, 1986.

Speth, Joseph, Los Alamos National Laboratory, "Large Momentum Transfer Electron Scattering & the Compression Modules of Nuclear Matter", July 2, 1986.

Detlev Bohle, THS Darmstadt, "Properties of an Orbital Ml Excitation Mode in Nuclei", August 21, 1986.

Rule, D. W., Naval Surface Weapons Center, "Transition Radiation Diagnostics for Intense Charge Particle Beams", August 21, 1986.

McDonald, K. T., Dept. of Physics, Princeton University, "Observation of Interference Between Cerenkov and Synchrotron Radiation", September 11, 1986.

LIST OF ACRONYMS

AAMI	Association for the Advancement fo Medical Instrumentation
AAPM	American Association of Physicists in Medicine
ACO	Orsay Electron Storage Ring/France
AERE	Atomic Energy Research Establishment (U.K.)
AFRRI	Armed Forces Radiobiology Research Institute
AIF	Atomic Industrial Forum
ALS	Advanced Light Source
ANL	Argonne National Laboratory
ANS	American Nuclear Society
ANSI	American National Standards Institute
APS	American Physical Society
ASTM	American Society for Testing and Materials
AVS	American Vacuum Society
$BaSO_4$	Barium Sulfate
BBU	Beam Breakup
BESSY	Berlin Electron Storage Ring Facility/Germany
Bevalac	Name of a heavy ion accelerator at Berkeley
BGO	Bismult generator
BIPM	Bureau International des Poids et Mesures (France)
BPNL	Battelle-Pacific Northwest Laboratory
CAD	Computer-aided Design
CAE	Computer-aided Engineering
CAM	Computer-aided Manufacturing
CAMAC	Computer Automated Measurement and Control
CCEMRI	Consultative Committee for Ionizing Radiations
CCG	Combined Calibration Group
CCPR	Consultative Committee on Photometry and Radiometry
CEBAF	Continuous Electron Beam Accelerator Facility/Newport News
CEN	Center for Nuclear Energy, Saclay, France
CERN	European Center for Nuclear Research (Switzerland)
CESR	Cornell Electron Storage Ring/U.S.A
CIE	Internatinal Commission of Illumination
CIPM	Committee International des Poids et Mesures
CIRRPC	Committee on Interagency Radiation Research and Policy Coordination
CNRS	French National Center for Scientific Research
CO_2	Carbon Dioxide
CORM	Council for Optical Radiation Measurements
CRCPD	Conference of Radiation Control Program Directors
CRDS	Charles River Data System
CRR	Center for Radiation Research
Cs	Cesium
CSEWG	Cross Section Evaluation Working Group
CW	Continuous Wave

DARPA	Defense Advanced Research Project Agency
DCM	A specific laser dye
DIAL	Differential Absorption LIDAR
DNA	Deoxyribos nucleic acid
DOE	Department of Energy
DOS	Disk Operating System
DSA	Digital Subtration Angiography
DTS	Dual thin scintillator
EC	Electron Capture
ENDF	Evaluated Nuclear Data File
EPA	Environmental Protection Agency
ETH	Swiss Federal Institute of Technology
ETL	Electro-Technical Laboratory (Japan)
EURADOS	European Community Dosimetry
FASCAL	Facility for Automatic Spectroradiometric Calibrations
FDA	Food and Drug Administration
FEL	Free Electron Laser
FEMA	Federal Emergency Management Agency
FERDoR	(computer code)
FIMS	Fissionable Isotope Mass Standards
FOS	Faint Object Spectrograph
FRG	Federal Republic of Germany
FT	Fourier Transform
FWHM	Full Width at Half Maximum
FY	Fiscal Year
GaAs	Gallium Arsenide
GC/MS	Gas chromatography/mass spectrometry
GPIB	General Purpose Interface Bus
GSFC	Goddard Space Flight Center
HAFM	Helium Accumulation Fluence Monitor
HgCdTe	Mercury Cadmium Telluride
HP	Hewlett Packard
HPGe	High-purity germanium detector
HPLC	High performance liquid chromatography
IAEA	International Atomic Energy Agency (Vienna)
IBM	International Business Machines Corp.
ICIAQ	Interagency Committee on Indoor Air Quality
ICPEAC	International Conference on the Physics of Electron and Atomic Collisions
ICRM	International Committee for Radionuclide Metrology
ICRU	International Commission on Radiation Units and Measurements
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronic Engineers
INEL	Idaho National Engineering Laboratory

INMM	Institute for Nuclear Materials Management
INSF	Intermediate Energy Standard Neutron Field
I/O	Input/Output
IPNS	Intense Pulsed Neutron Source
IPTS	International Practical Temperature Scale
IR	Infrared
ISO	International Organization for Standards
ITP-UCSB	Institute for Theoretical Physics - University of California, Santa Barbara
JAERI	Japan Atomic Energy Research Institute
JEN	Junta de Energia Nuclear (Spain)
JET	Joint European Torus
JILA	Joint Institute of Laboratory Astrophysics
KEK	National Laboratory for High Energy Physics (Japan)
KENS	High Energy Neutron Source (Japan)
KRI	Khlopin Radium Institute (USSR)
LANL	Los Alamos National Laboratory
LASP	Laboratory for Astronomy and Space Physics/U. of Colorado
LDEF/ITS	Long Duration Exposure Facility/Integrated Target Satellite
LEED	Low Energy Electron Diffraction
LET	Linear Energy Transfer
LIDAR	Laser Detection and Ranging System
LINAC	Linear Accelerator
LLNL	Lawrence Livermore National Laboratory
LTEC	Lamp Testing Engineer's Conference
LURE	Laboratory for the Use of Energetic Radiation/Orsay, France
LWIR	Long Wavelength Infrared
μm	Micrometer
mm	Millimeter
MCNP	(computer code)
MFKI	Research Institute for Technical Physics (Hungary)
MIT	Massachusetts Institute of Technology
MQA	Measurement quality assurance
MRG	Materials Research Group
MRTD	Minimum Resolvable Temperature Difference
NASA	National Aeronautical and Space Administration
NAS-NRC	National Academy of Sciences-National Research Council
NATO	North Atlantic Treaty Organization
NAVLAP	National Voluntary Laboratory Accreditation Program
NBS	National Bureau of Standards
NBS-PC	NBS-Personal Computer
NCRP	National Council on Radiation Protection and Measurements

NDT	Non-Destructive Testing
NIM	Nuclear Intrumentation Module
NIR	Near Infrared
nm	Nanometer
NML	National Measurement Laboratory
NPL	National Physical Laboratory
NRL	Naval Research Laboratory
NRRS	Near resonance Rayleigh scattering
NSF	National Science Foundation
NSLS	National Synchrotron Light Source
NTOFF	Neutron Time-of-Flight Facility
OD	Outside Diameter
OMEGA	24 Beam Laser Facility at Rochester
OMH	Hungarian Office of Measures
ONR	Office of Naval Research
ORNL	Oak Ridge National Laboratory
OSA	Optical Society of America
PC	Personal Computer
PID	Post irradiation dosimetry
PN	p on n type silicon junction
PNL	Battelle Pacific Northwest Laboratories
PRC	Peoples Republic of China
PRT	Proton recoil telescopic
PSD	Photon Simulated Desorption
PTB	Physikalisch Technische Bundesanstalt (West Germany)
PTFE	Polyetrafluoroethylene
PTW	Physikalisch Technische Werkstätten
QED	Quantum electrodynamics
RAM	Random Access Memory
RARAF	Radiological Research Accelerator Facility
RDS	Resonance detector spectrometer
RF	Radio Frequency
RTM	Racetrack Microtron
SCA	Sphere-Chain Attenuator
SCK-CEN	Studiecentrum voor Kernenergie-Centre d'Etude de l'Energie Nucleaire (Belgium)
SDIO	Strategic Defense Initiative Office
SEM	Scanning Electron Microscope
SEMPA	Scanning Electron Microscopy with Electron Polarization Analysis
SIRIS	Sputter Initiated Resonance Ionization Mass Spectrometry
SLAC	Stanford Linear Accelerator Center
SNS	Spallation Neutron Source
SPIE	The Society for Photo-Optical Instrumentation Engineers
SRC	Synchrotron Radiation Center, UK

SRM	Standard Reference Material
SSTR	Solid State Track Receiver
STM	Scanning Tunneling Microscope
STOS	Space Telescope Optical Simulator
SUNY	State University of New York
SURA	Southeastern Universities Research Association
SURF & SURF-II	Synchrotron Ultraviolet Radiation Facility
SUSIM	Solar Ultraviolet Spectral Irradiance Monitor
SW	Standing Wave
TAMS	Tandum Accelerator Mass Spectrometry
TEPC	Tissue Equivalent Proportional Counter
TEXT	Texas Experimental Tokamak
TLD	Thermoluminescent Detector
TRIGA	(research reactor design made by General Atomic)
TUD	Technical University of Dresden (East Germany)
TW	Traveling Wave
UDT	United Detector Technology, Inc.
UK	United Kingdom
UNH	University of New Hampshire
UPS	Ultraviolet Photoemission Spectroscopy
USADC/SDI	U.S. Army Defense Command/Strategic Defense Initiative
USDA	United States Department of Agriculture
USUHS	Uniformed Services University of Health Sciences
UV	Ultraviolet-Wavelength Range 200-400 nm
UVA	University of Virginia
UVSG	Ultraviolet Spectrometry Group
VUV	Vacuum Ultraviolet-Wavelengths less than 200 nm
VIAS	(computer code)
VIS	Visible
VME	(computer bus system)
XT	A type of personal computer
XUV	Extremely Far Ultraviolet
XUV	Soft X-Ray Wavelength Range, 10-50 nm
WNR-PSR	Weapons Neutron Source-Proton Storage Ring

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